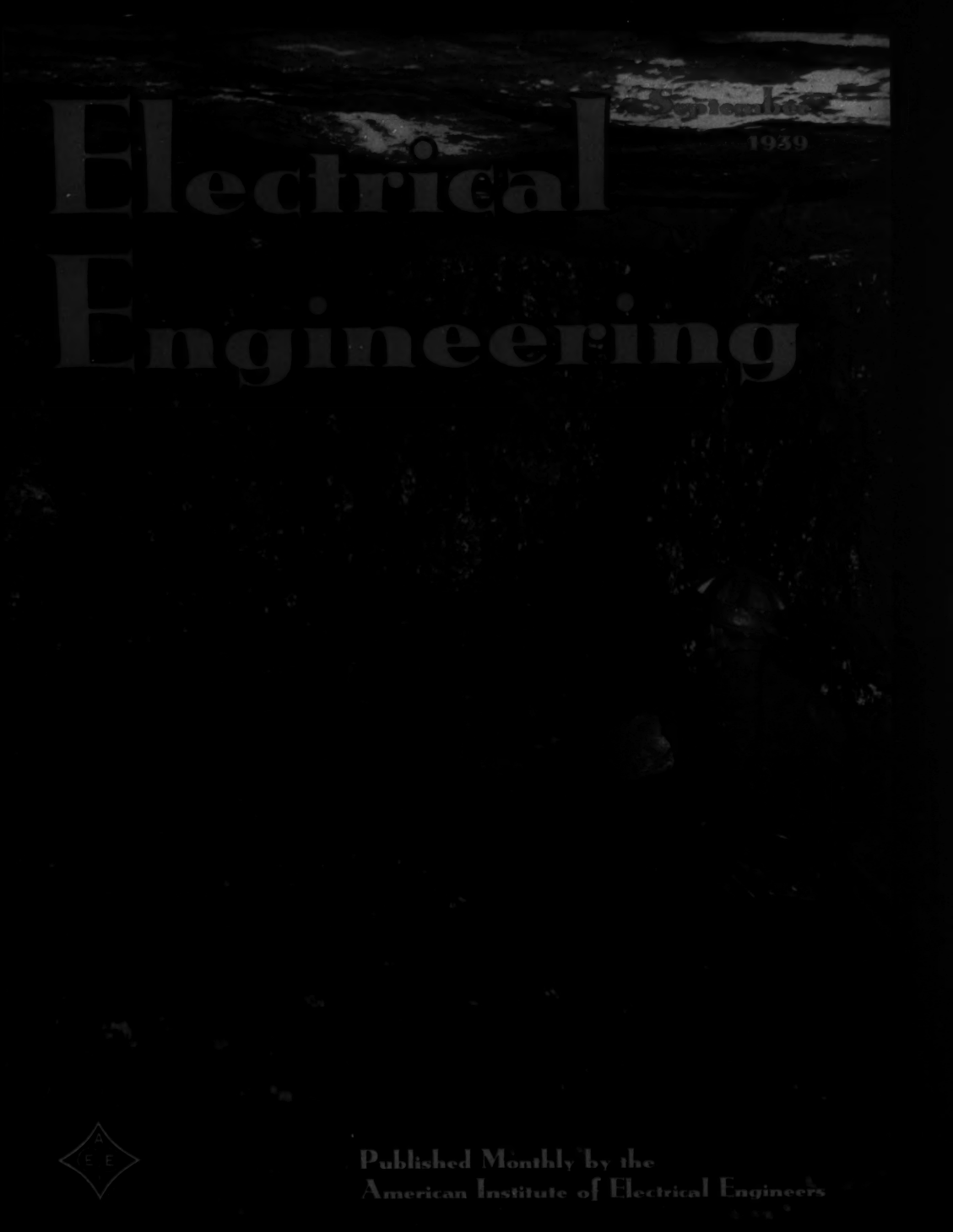

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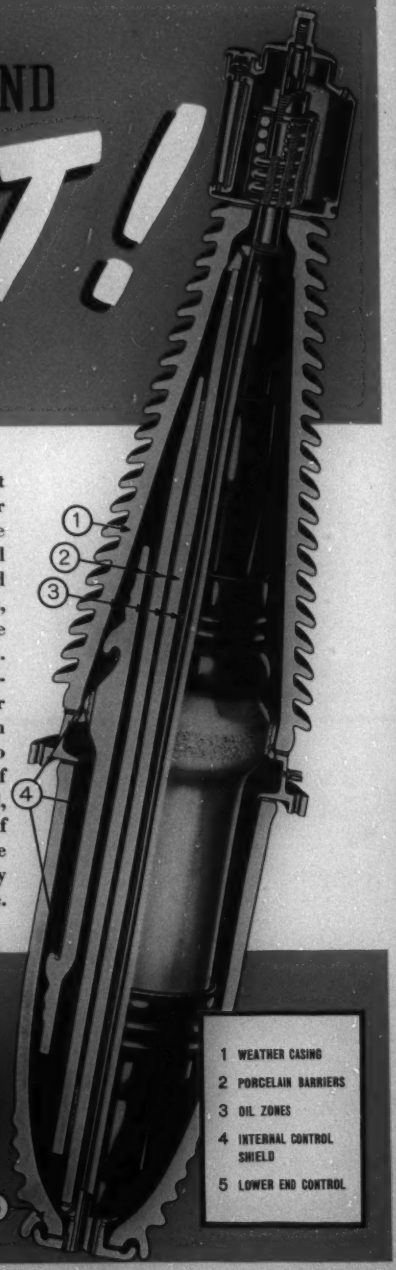

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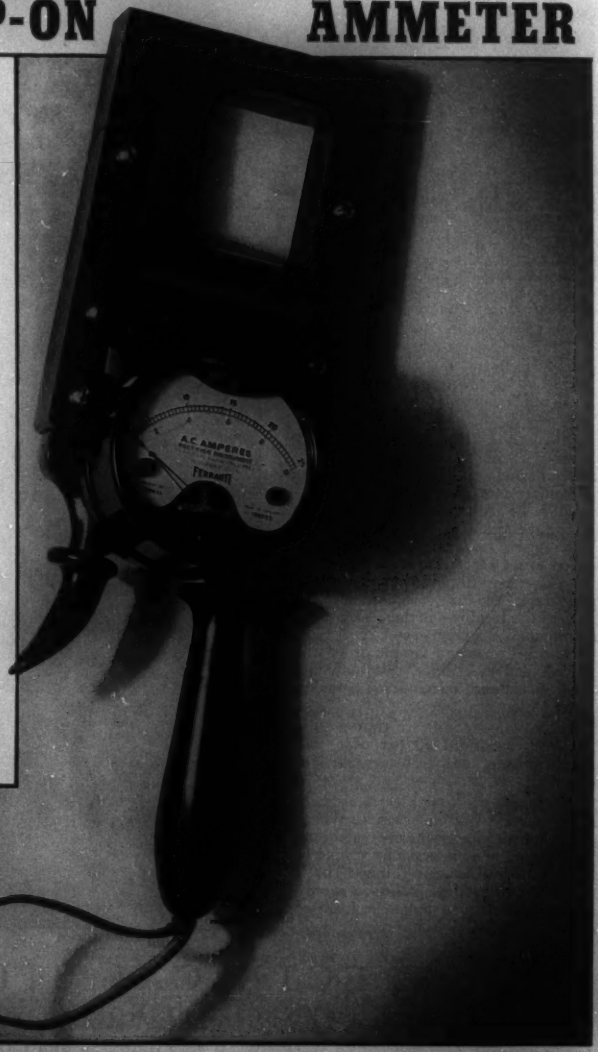

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WRITE FOR BULLETIN 459

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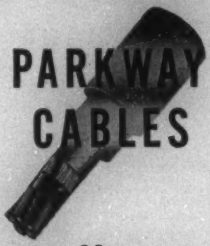

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Electrical Engineering

Registered U. S. Patent Office

for September 1939—

The Cover: Undercutting—the first application of electricity to the actual mining of anthracite coal. Various aspects of the use of electricity in this industry will be discussed at the AIEE Middle Eastern District meeting to be held at Scranton, Pa., October 11–13, 1939.

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¶ Correspondence is invited on all controversial matters.

High Lights

Temperature Rise. Measurement of temperature rise in induction motors is necessary to determine ratings, and AIEE standards recognize three methods: thermometer, resistance, and embedded detector. Some of the methods are not applicable to certain types of modern motors, and therefore recommendation is made that the resistance method be adopted as standard for partially or totally enclosed induction motors (*Transactions pages 459–67*). Because location of thermometers depends upon the judgment of the tester, extension of the use of the resistance method to all induction motors is urged, with the necessary revision of standard temperature ratings and conventional allowances for hot-spot temperatures (*Transactions pages 468–78*).

Rating of Motors. Both mechanical and thermal output limitations must be recognized in a system for rating of electric motors, any such system being arbitrary and dependent upon the service conditions. The increasing variety of motor uses and economic pressure have led to the use of overload capacity in small motors beyond the continuous ratings, and therefore a revision of American standards for general-purpose motors is proposed to enable the full economic life of motors to be utilized (*Transactions pages 445–59*).

Temperature Limits. Oil and cellulose insulation deteriorate rapidly when certain temperatures are exceeded, and hence set a limit to the ratings of electrical apparatus. Life tests now indicate that cellulose will undergo very little deterioration up to approximately 90 or 95 degrees centigrade in the absence of oxygen, and that ratings of apparatus from which oxygen is largely excluded may be higher than if free breathing were permitted (*Transactions pages 484–91*).

Social Responsibility. Declaring that it is "essential to the maintenance of a democratic society and to progress in solving baffling social problems to have the talents and active citizenship of engineers focused upon those problems," an engineering educator places upon the college the responsibility for developing habits, interests, and competences which will enable the engineer to co-operate with other citizens who are working toward the same ends (*pages 367–71*).

Middle Eastern District Meeting. Applications of electricity to mining will be discussed in a technical session, and a visit to an anthracite-coal mine is featured among inspection trips at the AIEE Middle Eastern District meeting, Scranton, Pa., October 11–13, for which four other technical sessions, a Student Branch convention, and a testimonial luncheon for Past-President Charles F. Scott (A'02, F'25, HM'29), are also scheduled (*pages 389–90*).

Human Relationships. At the general session of the recent AIEE combined summer and Pacific Coast convention a prominent power-company executive discussed some of the human relationships involved between management and workers, business and its customers, and business and government. He says that the critical developments of the past ten years are again bringing human values to the fore (*pages 371–3*).

AIEE Model Law. The draft of a model law for registration of engineers prepared by the AIEE special committee on model law and approved by the board of directors at its meeting in San Francisco, June 29, 1939, is published for consideration by AIEE members, together with a statement of the principles underlying the law and an introduction by the chairman of the special committee (*pages 374–9*).

Aging of Insulation. Organic insulating materials deteriorate progressively when maintained continuously at elevated temperatures. One result of a laboratory investigation of aging is substantiation of the reasonableness of 105 degrees centigrade as the maximum hot-spot temperature for purposes of standardization (*Transactions pages 435–44*).

Great Lakes District Meeting. Technical sessions on communication and research, electrical machinery and transportation, measurements, power transmission and distribution, are included in the program of the AIEE Great Lakes District meeting, Minneapolis, Minn., September 27–29, as well as a Student Branch convention, inspection trips, and entertainment (*pages 391–2*).

Magnet-Wire Insulation. Synthetic materials have come to occupy an important place in the insulation of electric conductors of all sizes, particularly magnet wire. A new synthetic-resin coating has properties that make it markedly superior to former enamel coatings (*pages 379–88*).

American Engineering Council. Among items appearing in the current AEC *Bulletin* are discussion of pending legislation for registration of engineers in the District of Columbia, and a survey of action taken at the last session of Congress for the improvement of patent procedure (*page 395*).

Past-President Scott to Be Honored. Among Institute activities commemorating the 75th birthday of Doctor Charles F. Scott (A'92, F'25, HM'29), will be a dinner meeting September 19, to be held by the Connecticut Section of which he was a founder and first chairman (*page 392*).

Voltage Correction. Choice of equipment for voltage correction on distribution circuits depends on the individual characteristics of the system, but the economic choice for one system may be representative for other similar systems (*Transactions pages 491–8*).

Motor Analogy. The problem of choosing a motor for a given duty cycle may be clarified by a hydraulic analogy that illustrates the relations between torque ability and temperature rise (*Transactions pages 478–83*).

Officers and Committees. Officers and committees chosen to serve the Institute during the year 1939–40 are listed in this issue. Listings of local Sections and Student Branches also are given (*pages 400–04*).

Coming Soon: Among special articles and technical papers now undergoing preparation for early publication are: an article on the nature, properties, and uses of polarized light, by L. W. Chubb (F'21); an article describing the Boulder-Chino 220-kv transmission line of the Southern California Edison Company, by Harold Michener (M'26); an article on a mechanical demonstrator of transmission-line surges by C. F. Wagner (M'27); an article on determination of optimum voltage for airplane electrical systems, by V. H. Grant (A'37) and M. F. Peters; a paper on the rating of electrical machinery and apparatus by R. E. Hellmund (F'13); a paper on loading transformers by copper temperature by H. V. Putman (M'32) and W. M. Dann (F'26); a paper discussing the effects of temperature on the mechanical performance of electrical machinery and apparatus by C. Lynn (A'38); a paper on the rating and application of motors for refrigeration and air conditioning by P. H. Rutherford (M'30); and papers on load ratings of cable by Herman Halperin (M'26) and maximum safe operating temperature for 15-kv paper-insulated cable by C. W. Franklin (M'24) and E. R. Thomas (M'30).

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Social Responsibility of the Engineer

ROBERT E. DOHERTY
MEMBER AIEE

WHETHER engineers should assume a larger measure of social responsibility has been debated extensively during the last decade with practical results that are not impressive, yet there appears to be significant crystallization of professed opinion. While the view still lingers here and there that the engineer should stick to his technical knitting, letting other professional men worry about the social consequences of his work, there is nevertheless a pervasive and growing opinion that he should play a more active part in the social realm and that his educational preparation should take this aim into account. However, the extent of the discussion and of apparent agreement upon this point is out of all proportion to the practical results, as measured either by active participation or by changes in educational programs looking to participation. Progress seems to be stymied biologically; after professional maturity, we seem to exhibit a certain elasticity of professed view but tend nevertheless to cling tenaciously to established habits. Not having participated, we don't start. Thus as a profession of engineers and educators we seem to agree upon principle, and more or less let it go at that.

There is significant evidence of this attitude. While a few national engineering societies appear interested in social values that might come from united effort, others seem indifferent. Witness the precarious status of the American Engineering Council, which is withering from lack of support; yet it represents the only national medium through which the engineering profession as a whole can serve national welfare as well as its own interests. And it is my understanding that the Council has done a good job within its means. Another example is the Engineers' Council for Professional Development. This is the only organization that is constituted by proper representation to lift the engineering profession on all fronts to the level that it deserves and that we all wish for. And it has made measurable beginnings in four important directions, as presumably you all know. Yet the reservations with which some engineering societies enter it indicate a significant attitude of self-sufficiency. Naturally it is not for me to question in the least their full right to any attitude they wish to assume. I am merely citing it as evidence to my point that the engineering profession, although tending to agree that the engineer's station in society should be higher and his responsibility greater, has not yet reached the point of doing much about it. Neither has the teaching profession, as a glance at engineering curricula will indicate. A few show some revision toward the end of greater social and humane understanding but by and large the portion of the curriculum assigned to this end is distressingly meager. Status quo tends to persist.

Meantime national life proceeds more and more precariously. While we tire of hearing tales of woe, the ugly fact is that strife and confusion characterize the American scene. Pressure groups fight for selfish advantage; political demagogues try to outdo each other in leading raids upon the public treasury; labor fights with employers and with itself; and government and business are at loggerheads. Although Theodore Roosevelt invented the "square deal," Woodrow Wilson the "new freedom," Hoover the "new era," and Franklin Roosevelt the "new deal," nevertheless, after a generation of political discovery and invention, the American people have become more baffled than ever in their efforts to incorporate the vast discoveries and inventions of science into their scheme of living, so that they might realize in peaceful, prosperous, and happy lives the limitless potentialities of these intellectual and material achievements. Individuals, groups, classes, and nations quarrel over the division of limited production instead of co-operating to provide an abundance for all; and they wantonly squander existing values and mortgage those of the future. Youth is discouraged; business men are confounded; trustees of great endowments don't know what to do; men without funds and men without work don't know what to do; nobody knows what to do!

What is the outlook? One's optimism is, I realize, likely to be adversely conditioned by immediate circumstances such as these I have just mentioned. On the other hand, the mere exhibition of optimism unfortunately is not very fruitful in an analysis; and whistling in the dark will not stop the lurking gangster. So for the next few minutes at least I may appear to assume the role of the pessimist, for I must confess that within my limited view there is little promise of long-range social felicity unless I postulate some new element that is not yet manifest in the body politic.

History is not reassuring. In his article "Are Revolutions Necessary" historian Guy Stanton Ford, now president of the University of Minnesota, said this:

> "To the question 'Must short-time and long-time changes end always in conflict and violence?' the historian can only answer with certainty that the clash between beneficiaries of the existing order and exasperated advocates of change has always so ended. Each time, resistance to modest reform is blind to the wisdom of concession and the necessity of change. If concessions are made, they come too late. The demands have risen and the price of peace is again too high, only to become again too cheap. The reactionary breeds the radical among reformers, the approaching conflict falls under the leadership of these two opposing extremes, and the conflict follows. The process has been repeated so often in so many fields that it appears inevitable and, historically speaking, necessary.
>
> "Have we before us any hope that mankind has, after all these

Address presented at the annual meeting of the Society for the Promotion of Engineering Education, State College, Pa., June 19–23, 1939.

ROBERT E. DOHERTY is president of Carnegie Institute of Technology, Pittsburgh, Pa., and has long been active in the AIEE, SPEE, and the Engineers' Council for Professional Development.

centuries, learned a way to make, without violent dislocation, the necessary readjustments in his relations to his material environment and his fellow man?"

To President Ford's answer that there may be hope if we can learn to be tolerant and maintain the sanctity of free press, free speech, and the scholar's immunity to pursue truth, I would add two other essentials: (1) that we learn to make practical use of a new power within our reach that the generations of history did not have—the power of reasonable prediction that may come from the scientific method if it be applied to social and economic problems with the same intelligence as it has been applied during the last few generations to physical problems; and (2) that in our democracy we find a way to accomplish widespread social interest and understanding among professional men. Tolerance is necessary, but understanding there must be also; the issues even in their simplest forms become too much for most untrained, uninformed minds. There must be here and there among the masses cultivated intellects that can understand and give support to informed decision. And there must be in the councils of the state and nation not merely professional expertness, but expertness fortified by broad social understanding and a willingness to co-operate.

I am clear that there is not a political panacea for our woes. Many feel that a less severe attitude by the national administration would be helpful, but I am confident that neither such an attitude nor a change of administration would solve the problem, because at bottom it is not political. It existed before the present administration came to office and will continue when a new administration comes to power. Social forces of the character and magnitude of those which now press us are not to be controlled by the fickle furor of partisan politics. Oscillating like a mighty, sweeping pendulum, they swing us back and forth with ever-increasing violence between glut and poverty. And it will take more than political oratory to deal with the situation.

The job of professional statesmanship is to see that an end be put to the political hand-to-mouth method of dealing with social problems, and that these be recognized and attacked early enough and intelligently enough so that people's minds may become *gradually* accustomed to the new ideas involved. Then perhaps necessary change may be effected without violence and chaos. It is my purpose during the next few minutes to outline how I think engineers should enter this situation: why they should assume greater social responsibility, what it might be, and how their active interest might be won.

The fundamental ground on which I believe engineers should assume greater social responsibility is the fact that, after all, we live in a democracy. I have found it difficult to elicit interest in this idea because there is a widespread inclination to regard allusions to democracy and competent citizenship as sentimental vapor—as something nice to talk about, especially on flag day, but not in serious meetings of the kind I take this to be. Such matters are left largely to primary and secondary schools. But I do hope we can set aside such insidious prejudices if we have them, because there is involved here a deeper significance than momentary patriotic fervor; a greater responsibility, especially for professional men, than merely voting, accepting majority rule, and understanding the machinery of government. Our question transcends these; it strikes at the heart of the matter. Lifted out of the welter of confusing elements, the question we must answer is whether in our thinking and planning in connection with the future of engineering and engineering education in this country we are ready sincerely to accept as a philosophical basis the principle of democracy. If we are not, then I recommend that we prepare our exit. If we are, then we are obliged, if we be rational, to accept the implications.

These are simple. If the people or their representatives are to settle questions of state and national concern, then certainly they must be competent to do so, or the whole system becomes a farce. Indeed it appears already to be approaching this. Issues have become too complex for the masses to understand; indeed they have become too complex for those whose business it is to understand and deal with them. By the very nature of the case, therefore, if we accept the theory of democracy we must accept also the proposition that there should be available to government at all its levels intelligent understanding and competence to deal with problems of statesmanship that have to be solved.

Such competence in a democracy cannot be confined to a capacity for balancing the relative advantages of different courses of action and approving that course which appears best; it must include as well competence in the use of present-day facilities for making these alternatives understandable to the voters by whom basic issues are decided. This requirement carries the problem into a field which scientifically trained men are frequently reluctant to enter—that of publicity and propaganda. But unless educated citizens are prepared to make themselves competent in this field for the benefit of society at large, their efforts, no matter how wisely conceived, will be overwhelmed by the propaganda of pressure groups who pursue selfish interests and who frequently have the skill to clothe these interests in the robes of patriotism and public welfare. Educated citizens must learn to explain social problems as well as to solve them.

To my mind, therefore, acceptance of the principle of democracy implies a new emphasis in education and a new sense of responsibility of citizenship on the part of professional men, not only as individuals but also as organized professional groups. It seems to me necessary that there be a pervasive infiltration, among the citizenry, of professional people who will have become socially literate and who will feel the responsibility that goes with advantage and privilege; and further that professional groups hold constantly and pre-eminently in view their status as organic units of a democracy now under stress and their responsibility to help save it for future generations.

Then there are other grounds, I contend, on which engineers have an especial responsibility. In proposing these grounds, however, I hope I need not disclaim the supposition that engineers are self-righteous and endowed with special intellectual gifts and that therefore as a pro-

fessional group they are the hope of the world. There are, however, two special facts regarding engineers that place them in a unique position, and I need do no more than mention them to this audience. One is that the very nature of their professional work affects social organization. For example, in industrial management where they hold forth, social and economic problems loom large. Moreover, their technical achievements are associated with the origin of basic social problems—for instance, immediate technological unemployment and the rapid, fundamental alteration of the physical environment of society. Thus being the authors of, and therefore intimately understanding, the causes themselves, they should be in an advantageous position to learn how to control the effects.

The other special fact is the effectiveness of the engineer's method. The care and objectivity with which he approaches a problem, his insistence upon understanding its elements as far as may be practicable before deciding upon plans, the impartiality of his decisions, the firmness of his execution—these are certainly something to be desired in social and economic affairs. The discipline of dealing with facts and principles that demonstrate themselves—sometimes publicly, if the bridge fails—has been widely and justly praised as a commendable attribute of the engineer's calling. So I am only repeating a commonplace when I propose that there is undoubtedly something in the engineering method, the scientific method, that is wanting in many social procedures and that could with great profit be exercised there. But believing this, I yet know that it would be putting the doctrine of transfer of ability to severe stress to move the engineer with his present knowledge and method over into the social realm without an appropriate leavening of his mind with humane appreciation and social understanding. But with this, I am confident that his method would greatly reinforce the attack upon those social problems that are related to his fields, or are a part of them.

Thus his method and the social implications of his work are cogent reasons for his assuming greater social responsibility; and added to these is the fundamental proposition that responsibility is doubly implied in democracy—through his citizenship and his organized professional connections.

What might that responsibility be? In what ways might the engineer become socially more serviceable? I have already indicated this in general terms. To be more specific brings one close to the realm of speculation. What, for instance, might the engineer actually do as an educated citizen? Just what every other educated citizen should do: Keep informed regarding public issues, arrive at intelligent convictions, and give these as forceful expression as possible by such means as may be at his command. These means obviously include active cooperation with other citizens in the promotion of causes which appear sound; helping the masses understand; and taking a much more extensive hand in public service in his local community, or in state or national affairs.

Moreover, engineers are increasingly forced to assume social responsibilities incident to their professional service. Managers and promoters of new technical undertakings must, willy-nilly, take account of the social consequences of alternative approaches to problems which have to be solved, and because the social and the technical aspects of these problems are interwoven, the two must be handled concurrently. The engineer who is blind to the social implications of his work is a less efficient engineer when social problems are involved than the one whose analysis includes necessary social factors, because whether we like it or not these have become a part of engineering activity. The engineer's achievements in management on the material, technical, and economic sides have been magnificent, and he has frequently rendered notable service on the social side of his undertakings. In other cases, however, social ills, avoidable and unavoidable, have accompanied engineering progress, and it has become clear that the engineer has an important responsibility in helping to ameliorate these conditions. And in the midst of management he certainly is in a most favorable location to do so.

And finally as a member of organized engineering groups he might together with his colleagues exert telling influence upon important national problems. Most certainly in those which involve engineering elements he should have a strong voice in the forming of policy as well as the responsibility for technical plans. And more general still, he should be represented on equal footing with other professions on commissions and councils of government that might work out intelligent recommendations regarding long-range policy on which legislative bodies or administrations might act. In other words, wherever intelligent group procedure is required in connection with the problems of the democracy, the engineer should be represented.

But what can be said of the view one occasionally meets that the engineer's business is engineering, and that social and economic matters should be left to the social scientist? There is no berth in my mind for this opinion for two reasons: It stretches too far the theory of the division of labor, and it contravenes the principle of democracy. Experience proves division of labor to be sound in the building of a gun or automobile, but not where the business is settling what human relationships and human interests should be. It is one thing to have the several operations of shaping and assembling material parts done independently by different individuals according to an organized plan, and quite another to try to make the general plan itself by that method. And this is what we are discussing. Of course we should say that the strictly technical business of the social scientist should be done by him, of the engineer by the engineer, and of every other profession by that profession. But there are two things we must not do. We must not try to bound professional fields by straight lines when the boundaries are inherently irregular zones; rather we must articulate effectively those protruding areas at the boundary that should extend continuously from one field to another so that the whole pattern might represent an integrated, organic, social unit. And secondly, we must not confuse expertness in a particular field with qualification for forming general judgments as to social policy and plan. The medical profession should

not itself decide whether we should have socialized medicine, but it should submit to a representative professional body the technical implications of such a policy; the legal profession should not itself decide upon laws, but certainly should deal with the technical business involved in their preparation and interpretation; the engineering profession should not itself decide whether we should have TVA, but certainly should make and interpret the results of its calculations; and the social scientist should not decide whether we should have a Federal Housing Authority, but should obviously make and submit his technical findings in relation thereto. Each profession must of course be responsible for technical expertness, and up to this point the theory of the division of labor is applicable; but no profession can be depended upon alone for judgments that involve interests and factors extending beyond its purview. And since there is not a super-profession—for most of us do not accord to social scientists this distinction—to which can be assigned the job of forming overall judgments and framing recommendations of wise policy and plan, the theory of the division of labor is found wanting at that point. Anyway, in a democracy, who is the social scientist to determine alone what social policy and plan should be? who the engineer? the business man? who indeed? None is competent. The job is too big, the ramifications of interest too extensive. But even if one were competent, it would contravene the principle of democracy to have proposed policy arrived at that way. Without a super-profession, and presumably without a dictator, to do our thinking for us, and yet with problems of social policy and plan so complex that expert professional thinking must be given to them, we are, it seems to me, inevitably committed to the more clumsy but democratic scheme of conference or council for reaching intelligent proposals in which the people, or legislative groups, might have confidence. Thus such councils would provide technical expertness, balance of interests, and the effective joining of boundary connections between related fields of social activity. All of these are essential and they cannot be achieved through the policy of professional isolation. The engineer cannot delegate his responsibility to the social scientist.

But it is idle to talk about social responsibilities which the engineer might assume unless there be some prospect of getting him interested. This is the crux of the matter. I do not have the answer, but I do have a theory. I am clear, in the first place, that there is very little prospect of getting him actively interested by talk. Discussion and exhortation seem ineffectual in exciting in mature man a new interest—one that will bring action along a line fundamentally different from that of the past. Why this is so is a matter for the biologist and psychologist; the explanation is not important here, but the fact itself is. Hence I see only little hope in discussion; most mature men are going to continue doing what they have done.

My theory is that active interest will follow competence. Given understanding and intellectual competence in the matter, interest will follow. If my observations are trustworthy, graduates follow essentially the interests they have cultivated in college; if not those within the immediate boundaries of the profession itself, then at least those of both subject matter and method that in college demanded a significant part of their attention. For illustration, in law such matters as social relationships and organization, business, finance, and discipline in careful statement are associated directly with the study of law itself. Graduates of law pursue legal practice, but they also gravitate to general management, politics, and banking. In medicine, on the other hand, there is little associated with the study of this field that is, at the same time, related so directly to fields outside the profession itself. And graduates of medicine, forming perhaps the most closely knit of the professions, stick close to medicine. In engineering again we have diversity. Planning based on clear-headed objective study and calculation, and the execution of plans, all in connection with material things—these have characterized the dominant interests of engineering students. And the graduates engage not only in technical pursuits, but also in industrial management and business. The question may be legitimately raised whether particular interests are pursued in college and afterward because they are inherent, or whether pursuit in college creates the interest. But the question has little point. The inference we have drawn is that whether the interest exists beforehand or is created, it is nevertheless cultivated in college and this cultivation profoundly influences the direction of later activity.

Here at least is a theory as to how the engineer's interest might be won. It means turning to youth; it means turning to education. If it is essential to the maintenance of a democratic society and to progress in solving baffling social problems to have the talents and the active citizenship of engineers focused upon those problems, habits must be formed in college, interests stimulated, and competences developed which will enable the engineer to co-operate naturally and effectively with educated citizens from other fields who are working toward the same ends.

This theory places responsibility for the initial step in the process squarely upon the shoulders of engineering educators, and this is a heavy and pointed responsibility. The initial step is difficult to take for reasons I have already stated, but unless we are to be in the position of shirking responsibility and of drifting in the face of danger under a policy of technical self-sufficiency, we must act. We must provide in the curriculum enough time and sufficient guidance of the right kind so that our engineering students will have reasonable opportunity to prepare themselves for the responsibilities they will meet in the day they reach professional maturity. If our national situation is difficult to understand and deal with, theirs will be more so; and we must help them get ready.

I need not repeat here the difficulties involved in the fundamental revision of the curriculum. Inadequate time, rigidity of view, vested interest, unwarranted insistence upon specialized skills and knowledge—all of these loom ominously at the first move toward change. I know what they are. But I am clear that we can immensely improve engineering education toward the ends of social understanding and at the same time toward the ends of engineering science and method, and still keep

the process within the present framework of undergraduate and graduate study.

I have just said that the responsibility upon engineering educators is heavy and pointed. Other professions may permit the creeping ossification of view to blind them in their mature years to the necessity of change and readjustment, but if the United States is to emerge from chaos and endure as a democracy, as a land of free men, then each new professional generation must be nurtured not in the same atmosphere and professional lore as their fathers and grandfathers but in the light and knowledge and purpose of their own day. And if this is to be so, then the teaching profession must make it so. The responsibility cannot be evaded.

Human Relationships

ADAM S. BENNION

Some of the human relationships involved between management and workers, business and its customers, and business and government are discussed here by a prominent power-company executive, who takes as his text the statement that "the strength of human feeling is still the most potent of all forces affecting the affairs of the world."

IT WAS my privilege to be in New York City on the day the King and Queen of Great Britain were tendered their great reception. I was not particularly surprised, therefore, when upon their arrival back home in London the King made the following remarkable statement:

"The detailed story of our travels is familiar to you by the daily press, the news reels, and the broadcasting corporations which, on both sides of the Atlantic, have reported it with accuracy and sympathetic understanding. I shall only try to tell you some of the impressions of my journey that remain in my mind. First, and deepest, is that even in this age of machines and mass production the strength of human feeling is still the most potent of all forces affecting the affairs of the world."

I take this statement as my text.

The history of the United States, brief as it is, is rich in achievement. We have faced problems of pioneering—of financing—of engineering—of construction—of selling—of accounting. All these are essential to the progress we have made. Just now, however, a new problem is conspicuous—not that it is entirely new, for it has always been important, but just now it is taking on added significance. Crises always serve to emphasize human relationships. That is true whether in the home, or in the school, or in the community. Crises test the fiber of men. When things go wrong it is natural for us to fix the responsibility—to blame somebody—to urge new panaceas. Certainly the difficulties of the last ten years have stirred up strife among men.

We have faced great human problems before. We faced them in the days of the American Revolution, when men fought for liberty. We faced them in the days when those same men struggled to formulate the foundations of our constitutional procedures. We faced these same problems in Civil War days, when men again fought to establish equality and to preserve our freedom.

In these last ten years men have been engaged in one more great struggle—this time for greater security and for a more equal share of the benefits of civilization. Civilization works in pendulum swings. For the last ten years we have been swinging in the direction of increased social privileges. Attempts have been made to safeguard men against unemployment, old age, sickness, and kindred dreads. America has been given a new social consciousness toward these responsibilities. In my judgment, business hereafter will always be more mindful of its human problems than it has ever been before. Unfortunately, sociological procedures are not quite so scientific as engineering procedures. No doubt we shall make mistakes. We need to counsel together on what I think is the biggest problem before America today: how to attain a sensible degree of social security without endangering the very principles upon which American civilization has been built.

Certainly that civilization has rested to date upon the driving force of individual initiative and freedom of enterprise. Whatever its shortcomings may be, American industry has built of this country the most outstanding nation in the world today. No totalitarian scheme can take credit for American achievement. No such scheme elsewhere in the world can match what America has done. The fact that problems exist should not lead us to destroy our pattern of living. Let's briefly look at some of our

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human relationships in an attempt to discover what the problems are and what may best be done about them.

FIRST of all, there is the problem of management and men. For some time I have been working in an organization which has recently been unionized, and therefore I come to you with full sympathy toward labor. I am convinced that working together men and management may build a great future. Working at cross purposes they can make progress impossible. The history of labor reveals very clearly that the laboring man is gradually coming into a better world. It is interesting to note that the summary of a survey of manufacturing institutions employing 8,000,000 men shows that in 1914 factory employes averaged 24¢ an hour; in 1937 the average was 71¢. In that same period their work week was cut from 51 hours to 40 hours. Whereas in 1914 they received a weekly pay check of $12.72, in 1937 they were getting a pay check 128 per cent higher. Then, too, men have been coming into a greater voice in the direction of the institutions with which they are connected. Great strides have been made since the days of slavery and serfdom. No doubt further adjustments will still be worked out. We need further understanding between management and men. Management needs to be more sympathetic; needs to be clearer in its provisions for the welfare of men. But men, also, need to be more mindful of the problems of management, its hazards, its responsibilities. In my judgment, if we ever needed in human relationships the genius of engineering technique, we need it right now. Men and management more than ever need to sit down around a common table to discuss their mutual relationships. These are not so simple as some men would have us believe. Management rests upon capital, and capital goes to work much as men do—only when the rewards justify it. Capital involves tremendously more than mere money; it involves creative ideas; it involves the genius of organization and managerial direction.

Statisticians are discovering that some $8,000 on the average must be invested to give employment to a single man. Money must be invested if men are to work. Idle money, lying in the banks—afraid to go to work or with returns so low that they do not encourage money to come out of the cellar—these things explain why so many men are idle in America today. It becomes increasingly clear that any program which threatens and browbeats money on the one hand and attempts to put men to work on the other is doomed to failure. The laboring man, in his own defense, should encourage the use of money at a reasonable return. It is foolish for men to condemn the agencies that in the last analysis must provide them the privilege of working.

There are other problems that need to be jointly thought through by management and men. Men need to know the costs involved in doing business—costs of the use of money; costs of rent; costs represented in taxes, in materials and supplies.

We talk a very great deal about profit-sharing. In all fairness we ought to talk also about loss-sharing, because the American plan of business is not just the profit plan—it is the profit-and-loss plan. Men need to be helped to understand more fully how wages are fitted into the general scheme of these costs. Then, too, further study needs to be made of the question of wages themselves. Who ought to be paid what and why? What is a man really worth? Measured in terms of responsibility, or of earnings, or of hazard, what should a given job pay?

Men generally are reasonable. They will want to do the fair thing when they understand. They need further to understand the complications of business. Management, too, must come into a fuller appreciation of its responsibilities to men. More careful study needs to be made of working conditions, of wage scales, of training on the job, and of provisions against sickness, accident, and old age. Certainly arbitrary rulings have been made in the past and human feelings all too frequently have been ignored. Together men and management can find sensible answers to all these problems. A willingness to give and take will find a solution to almost any one of them. Certainly it is primitive to proceed on a basis of shutdowns, layoffs, arbitrary disciplining on the part of management. It is equally primitive to resort to strikes and picketing on the part of men. Reason and sympathetic understanding are still our best guarantees toward a sensible answer in this first field of human relations.

THERE is a second outstanding problem in the field of industry—the relationship between institutions and their customers. After all, institutions are set up to be of service to people. It is an odd thing to witness the spectacle of institutions condemning the people they serve, or of people stirred to hatred against the institutions which would serve them. Unfortunately, when the crack-up of 1929 occurred, business was charged with the major responsibility for the failure. Men and women have been taught not only to distrust business, but to hate it; and yet the prosperity of America is the prosperity of her business institutions. Confidence is the keynote either to recovery or to sustained progress.

We are gradually learning, too, that businesses go hand in hand. Whenever one fails, all others are made to suffer.

I pay my tribute, in passing, both to the men in business and to the customers whom they serve. Both groups, by and large, are fair. Again it is a question of mutual understanding. There is no magic about public relations. There is no new panacea and no new device that will work out free from difficulties. Business needs to be more mindful of its customers; needs to do a better job of service; needs to treat its customers more as guests. May I quote one of the best statements I have yet encountered in the field of improved relationships between institutions and their customers:

"It is no longer sufficient that business produce goods or services of the kind customers want at a price that customers can pay. Although heaven knows that in itself is hard enough to do. In addition—and here we break into a new field of management re-

sponsibility—business must provide and dispense those goods and services in a manner to win general approval and under circumstances that will promote social as well as economic progress. The great lesson that business is learning is that people are interested in more than just the product and the price. They are interested in the way things are done, in what might be called the social products of industry.

"Defined broadly, good relations with the consuming public is not something that industry can achieve through publicity or through the activities of a particular department of the organization. Public relations is not a specialized activity like production, engineering, finance, sales. It is rather something that cuts through all these as the theme for each. It is an operating philosophy that management must seek to apply in everything it does and says. It is the philosophy of saying sincerely things people like—and saying them the way they like. It is more. It is the philosophy of doing things people like—and doing them the way they like. And, remember this, the doing is more important than the saying. But the doing alone is not enough."

(—*Paul W. Garrett, General Motors Corporation*)

Would you read further into this field, turn to "Ten Ways to Make Your Customers Like Your Company," by James E. Davidson (A'17, M'17), president of the Nebraska Power Company (*Bulletin* of the Edison Electric Institute, volume 6, 1938, pages 284–6).

SO FAR we have touched briefly on two of the outstanding problems in the field of human relationships: the problem of management and men, and the problem of the relationship between institutions and their customers. May we turn now, briefly, to a third consideration, namely, the relationship between business and government.

No one can face the developments of the last few years and not be aware that that is one of the greatest problems in America. There was a time, if I can clearly read the history of my country, when the primary business of government was to do what men could not do for themselves. Now there seems to be a tendency to let government do whatever government may aspire to do. Business finds itself in competition with its government at so many turns nowadays that one really wonders whether government proposes to take over the whole field of business. It is interesting to review the story of Egypt, and of Assyria, and of Babylonia, and of Greece, and of ancient Rome. All that happened to those countries should lead us to pause. We have had our constitutional government for only 150 years. We are a young nation as civilization is chronicled, and yet, we are following the tendencies that have cracked up all the civilizations referred to. They cracked up economically. They rolled up tremendous debts from which they could find no release. In our own country we have piled up a tremendous debt. Our government has entered into fields of competition with scores of its industries. There is a growing disposition to center more and more of our activities in Washington. I don't argue that the government cannot run the railroads or the telephones. I am aware that the government can operate the power business. The government, too, can furnish us with food and clothing, if it chooses. But once the government does all these things, American democracy becomes a memory.

Let me illustrate out of my own field. Certainly there the government has overreached its original boundaries. In the name of a yardstick experiment it has plunged into a program with the Tennessee Valley Authority which threatens to socialize the whole power program. You hear no more of the yardstick these days. Evidently it has been lost in the schemes of reforestation, of flood control, and of social rehabilitation. Let's look at a concrete example. The government is faced with the problem of flood control, or of reclamation. In the natural course of its development it must build a dam. A natural result is the production of power. I have no quarrel with the program up to that point; but when the power is produced, what need is there for the government to set up its own agency for distribution when to do so it must destroy agencies that have already done the work of pioneering and of building up the territory? Does the government say, "The costs are out of line"? Certainly these costs can be determined and controlled without crucifying existing institutions. Does the government say, "We must extend service to the frontiers"? Certainly that is a worthy purpose. But the government, again, can do this work of reaching out to the far corners either by way of gifts or by way of subsidies to agencies already established. In the American scheme of things it is always fine to see that we have an umpire to see that the game is played fairly. It is an American practice in baseball, basketball, tennis, and football. But when Uncle Sam aspires to play left halfback on the football field—when he takes the ball under his arm and heads toward the goal—at the same time presuming to be the umpire—sooner or later that practice will develop into a rotten game.

In order that this may not stand as a mere negative criticism, may I close this discussion with a few constructive suggestions which, in my judgment, will promote the relationship between government and business:

First, let the government concern itself with problems that everybody will agree belong to it, such as national defense, highway construction, reforestation, and the preservation of law and order.

Second, let it withdraw from activities in which it finds itself in competition with private agencies already established and doing a creditable job.

Third, if it desires to extend benefits and services, let the government do so through agencies that have already been built up in the spirit of American industry and that to date have made this country possible, and that now propose to sustain it.

Fourth, let the government cease its industrial indictments and its appeals to class animosities.

Fifth, let the government set industry free to expand not in words only, but in performances that make its words ring true.

Much has been said in recent years about driving money changers from the Temple. I am aware of that quotation. But it does not represent its Author at His best. That same Man, under the stress of a very vexing situation, declared as He meditated: "He that is without sin, let him cast the first stone."

In this good land of ours, in the spirit of Him who is responsible for both statements, we need a little less of the reformer and a lot more of the Redeemer.

Principles Underlying the AIEE Model Registration Law

1. Legislation of this type is enactable only for the public benefit and should be limited to that objective. Any benefit to the profession should be incidental.

2. Legislation is prefaced with statement of purpose. The purpose of enactments on engineer licensing usually reads "in order to safeguard life, health, and property." Enactments should avoid embodying provisions beyond the stated purposes and for unnamed ulterior objectives because such provisions would depart from the basic principle of truth which is the keystone of ethical engineering practice.

3. Public benefit will be protected in the maximum possible degree if it is assured that those who offer engineering services to the public are competent to render the service contemplated. Legislation can assure that certain minimum standards of competence exist and can provide for enforcement. It cannot attempt more than this. The public must determine for itself any necessity for competence in excess of the minima. Higher development of engineering competence beyond these minimum requirements continues to be the objective of engineering educational institutions and engineering societies, and its attainment is assured without legal requirement.

4. To assure these conditions it is not necessary that all engineers be subject to legislation but only those who offer service for hire, or are public employees.

5. The practices of engineering may be broadly classified as:

A. Those in which engineering service is the final objective as a business enterprise and for profit.

B. Those in which engineering is but one of several elements in the final product of an enterprise.

6. In classification A the engineer must assume final responsibility. In this class are the so-called "professional engineers" who offer professional service to the public for hire, either to individuals of the public or who are engaged in the execution of *public* projects as employees of the State or of the political subdivisions thereof.

7. In classification B the responsibility lies with the organization as a whole. In this class are the engineers (research, design, planning, or construction), for example, in the employ of manufacturers, utilities, and educational institutions. Here engineering is the means to an end. The final decisions and responsibility lie with these legally responsible corporations and are exercised by their executives as to the work of all employees including engineers.

8. Intermediate between these two groups is the structural engineer who is responsible, even as an employee, for approving or filing plans for structures in which the public safety is involved.

9. That the benefit of the public is served by regulation of engineers of classification A and of the structural engineer is clearly evident. That it is served by regulation of the employee engineer of classification B is not evident.

10. In neither of the frequently cited professions of law and medicine is regulation employed except of those in public relation. The misunderstandings arise probably from the relatively small fraction of those other professions which is not in public relation as compared with the large proportion of the engineering profession without public relation.

11. It may well be that some engineers not in public relation will, for their own reasons, elect to register under provisions of the enactment, but the choice should be with them individually.

12. The effect of legislation should be the fixing of a minimum engineer competence as the result of engineering training and experience in practice. There should be no attempt in this legislation to grade institutions, nor to control curricula and degrees and matriculation. The determination of curricula should lie within the educational institutions. Legislation should not be designed to limit the development of engineering schools nor the matriculation of engineering students, nor to promote the economic and social status of the engineer.

13. There should be no objective in legislation of control of the engineering societies and their grades of membership, nor of requiring registration as a condition of membership.

14. Reciprocity between States in admitting registered engineers to practice elsewhere than in the State of their registration should be encouraged.

15. The cost of licensing should be lowered. Proper budgetary control of expenditures should be provided.

16. Minimum curricula and experience requirements common to various branches of engineering and affecting public interest should be set up. Further examinations of applicants in various branches should be pertinent only to that branch of engineering in which they specialize and practice.

November 15, 1937

A Model Law for the Registration of Engineers

C. R. BEARDSLEY
FELLOW AIEE

AT THE summer convention meeting of the AIEE board of directors June 29, 1939, at San Francisco, Calif., the June 1, 1939, AIEE draft of Model Law for Registration of Engineers was adopted by unanimous vote. Therefore it appears timely to outline the origin and development of this draft, and to indicate how it may be used.

The AIEE has been represented for many years on joint committees drafting model laws for the licensing of engineers. Institute representatives have not endorsed in entirety any of the various drafts that have been prepared. The reason preventing endorsement was the belief that the model law for licensing engineers should limit the licensing requirement to cases where the protection of the public safety, health, and property is involved and should not require the licensing of all engineers regardless of whether or not they have direct relationship to those public questions. In the case of electrical engineering, a predominating proportion of the work is of such nature that licensing has no justification insofar as protection of the public is concerned. A licensing law should not be designed as a means for achieving or increasing professional unity. These considerations are set forth more fully in the statement of principles appearing on the facing page.

The AIEE board of directors, therefore, has not approved any of the drafts prepared by the joint committees to which it has sent representatives. Those drafts did not provide sufficiently for exemption.

In 1937 the AIEE board of directors authorized the preparation of a draft of a model law. A committee was appointed, consisting of C. R. Beardsley, *chairman*, T. F. Barton, and H. S. Osborne. The preliminary statement of principles was unanimously endorsed and became the basis of the draft. Mimeographed copies comparing this draft with the earlier drafts of the joint committees were sent to AIEE Sections for comment. Suggestions and comments were considered by the committee and as far as feasible were incorporated in the draft adopted at San Francisco and printed on these pages.

In states which already have adopted laws, this draft may prove useful in considering the amendments frequently proposed in state legislatures. AIEE Sections may decide to appoint committees on legislation to watch such amendments and take appropriate action on local matters. Such action, limited to local problems, issues, and initiative, should not involve the national organization.

In states where no laws exist, but may be in prospect, the AIEE Model Law may be useful to those engineers whose influence may be brought to bear in formulating proposed statutes.

The AIEE committee on Model Law has been merged with and has become a subcommittee of the Institute's committee on legislation affecting the engineering profession. Sections are encouraged to refer criticism or questions for advice to this committee.

June 1, 1939, AIEE Draft of a Model Law

TITLE: An Act to regulate the practices of professional engineering and land surveying,† creating a State Board of Registration for Professional Engineers and Land Surveyors, defining its powers and duties, imposing certain duties upon the State and political subdivisions thereof in connection with public work, and providing penalties.

Section I. General Provisions*

Be it enacted by the General Assembly of the State of ....., that in order to safeguard life, health, and property any person practicing or offering to practice professional engineering or land surveying[1] shall hereafter be required to submit evidence that he is qualified so to practice and shall be registered as hereafter provided; and it shall be unlawful for any person, not duly registered under the provisions of this Act, to practice or offer to practice in this State professional engineering or land surveying as defined in the provisions of this Act, or to use in connection with his name or otherwise assume use or advertise any titles or description implying that he is a professional engineer or land surveyor.

Section II. Definitions

Engineer: The term engineer as used in this Act shall mean a professional engineer as hereinafter defined.

Engineering: The term engineering as used in this Act shall mean professional engineering as hereinafter defined.

*Public employment:** The term public employment as used in this Act shall mean engagement in the execution of public projects as employee of the State or of a political subdivision thereof.

*Professional engineer:** The term professional engineer as used in this Act shall mean a person who is qualified and registered[2] under the provisions of this Act to engage in the practice of professional engineering as hereinafter defined.

*Professional engineering:** The practice of professional engineering within the meaning and intent of this Act includes any pro-

† In States where it is considered unconstitutional to include surveyors in the same registration act with engineers, a separate act should be prepared for surveyors and the necessary changes made in this Act so that it will provide for engineers only.

* Asterisks occurring throughout this draft indicate difference in intent from the August 1938 draft.

1. Land surveying does not involve matters that would ordinarily jeopardize life and health, but property rights are vitally affected by land surveying, and many States have deemed it essential to place restrictions and safeguards about its practice. Surveying is a function of engineering, but land surveying deals with land measurements involving property rights.

2. The words "and registered" were added because the fact of a person being qualified does not in itself make him subject to registration. Whether or not he is a professional engineer depends on the use he makes of his ability and experience. Certain private employments of engineers may be similar in functions to those of professional engineering yet should not render engineers in private employment subject to the requirements of registration.

fessional service for hire to the public or in public employment, such as consultation, investigation, evaluation, planning, design, or responsible supervision of construction or operation, in connection with any structures, buildings, machines, equipment, processes, works, or projects, wherein the safeguarding of life, health, or property is concerned or involved when such professional service requires the application of engineering principles and data.[3]

Land surveyor: The term land surveyor as used in this Act shall mean a person who engages in the practice of land surveying as hereinafter defined.

Land surveying: The practice of land surveying within the meaning and intent of this Act includes surveying of areas for their correct determination and description, for conveyancing, or for the establishment or re-establishment of land boundaries and the plotting of lands and subdivisions thereof.

Board: The term "Board" as used in this Act shall mean the State Board of Registration for Professional Engineers and Land Surveyors, provided for by this Act

Section III. Board: Appointment, Terms*

A State Board of Registration for Professional Engineers and Land Surveyors is hereby created whose duty it shall be to administer the provisions of this Act. The Board shall consist of five professional engineers, who shall be appointed by the Governor from among nominees recommended by a panel of engineering societies selected by the Governor of this State and shall have the qualifications required by section IV. The members of the first Board shall be appointed within ninety days after the passage of this Act, to serve for the following terms: one member for one year, one member for two years, one member for three years, one member for four years, and one member for five years, from the date of their appointment, or until their successors are duly appointed and qualified. Each member of the Board shall receive a certificate of his appointment from the Governor and before beginning his term of office shall file with the Secretary of State his written oath or affirmation for the faithful discharge of his official duty. Each member of the Board first appointed hereunder shall receive a certificate of registration under this Act from said Board. On the expiration of the term of any member, the Governor shall in the manner hereinbefore provided appoint for a term of five years a registered professional engineer, having the qualifications required by section IV, to take the place of the member whose term on said Board is about to expire. Each member shall hold office until the expiration of the term for which such member is appointed or until a successor shall have been duly appointed and shall have qualified.

3. The essential thought of this paragraph is that licensable engineering is characterized and defined by its employment for hire by the public. It is in such employment that the safety, health, and property of the public require the protection inherent in competent engineering service. The words "public welfare" used in other drafts were excluded as being indefinite and susceptible to too broad interpretation. This clause originally included words "public or private utility" but the definition was deemed complete without them. Also there is variation in the meaning of this term and confusion might result therefrom.

Section IV. Board: Qualifications

Each member of the Board shall be a citizen of the United States and a resident of this State, and shall have been engaged in the practice of the profession of engineering for at least 12 years, and shall have been in responsible charge of important engineering work for at least 5 years. Responsible charge of engineering teaching may be construed as responsible charge of important engineering work.

Section V. Board: Compensation, Expenses

Each member of the Board shall receive the sum of $..... per diem when actually attending to the work of the Board or any of its committees and for the time spent in necessary travel; and, in addition thereto, shall be reimbursed for all actual traveling, incidental, and clerical expenses necessarily incurred in carrying out the provisions of this Act.[4]

Section VI. Board: Removal of Members, Vacancies

The Governor may remove any member of the Board for misconduct, incompetency, neglect of duty, or for any other sufficient cause. Vacancies in the membership of the Board shall be filled for the unexpired term by appointment by the Governor as provided in section III.

Section VII. Board: Organization and Meetings

The Board shall hold a meeting within 30 days after its members are first appointed, and thereafter shall hold at least ..... regular meetings each year. Special meetings shall be held at such time as the bylaws of the Board may provide. Notice of all meetings shall be given in such manner as the bylaws may provide. The Board shall elect or appoint annually the following officers: a chairman, a vice-chairman, and a secretary.[5] A quorum of the Board shall consist of not less than three members.

Section VIII. Board: Powers*

The Board shall have the power to adopt and amend all bylaws and rules of procedure, in accordance with the Constitution and Laws of this State, which may be reasonably necessary for the proper performance of its duties and the regulations of the proceedings before it.[6] The Board shall adopt and have an official seal.

In carrying into effect the provisions of this Act, the Board, under the hand of its chairman and the seal of the Board, may subpoena witnesses and compel their attendance, and also may require the production of books, papers, documents, and so forth, in a case involving the revocation of registration or practicing or offering to practice without registration. Any member of the Board may administer oaths or affirmations to witnesses appearing before the Board. If any person shall refuse to obey any subpoena so issued, or shall refuse to testify or produce any books, papers, or documents, the Board may present its petition to such authority[7] as may have jurisdiction, setting forth the facts, and thereupon such authority shall, in a proper case, issue its subpoena to such person, requiring his attendance before such authority and there to testify or to produce such books, papers, and documents, as may be deemed necessary and pertinent by the Board. Any person failing or refusing to obey the subpoena or order of the said authority may be proceeded against in the same manner as for refusal to obey any other subpoena or order of the authority.

4. The per diem allowance of members of the Board is not indicated nor is it intended to be fixed as a commensurate compensation for the services to be rendered. High-grade professional men are expected to serve as a matter of good citizenship.

5. It is deemed advisable to have a member of the Board fill the office of secretary, but as provided in section IX, the Board may appoint an assistant secretary, executive secretary, treasurer, or other officer, not a member of the Board, to whom clerical and administrative duties may be assigned.

6. The phrase "in accordance with" existing laws confines bylaws and interpretations to the provisions of enactments. To authorize a board to adopt rules "not inconsistent with" existing laws permits wide latitude in power of new extensions of interpretation.

Section IX. Board: Receipts and Disbursements*

The secretary of the Board shall receive and account for all moneys derived under the provisions of this Act, and shall pay the same monthly to the State Treasurer, who shall keep such moneys in a separate fund to be known as the "Professional Engineers' Fund." Such fund shall be kept separate and apart from all other moneys in the Treasury, and shall be paid out only by .....[8] All moneys in the "Professional Engineers' Fund" are hereby specifically appropriated for the use of the Board. The secretary of the Board shall give a surety bond to the State in such sum as the Board may determine. The premium on said bond shall be regarded as a proper and necessary expense of the Board, and shall be paid out of the "Professional Engineers' Fund." The secretary of the Board shall receive such salary as the Board shall determine in addition to the compensation and expenses provided for in section V. The Board may employ such clerical or other assistants as are necessary for the proper performance of its work, and may make expenditures of this fund for any purpose which in the opinion of the Board is reasonably necessary for the proper performance of its duties under this Act, including the expenses of the Board's delegates to annual conventions of, and membership dues to, the National Council of State Boards of Engineering Examiners. Under no circumstances shall the total amounts of warrants issued by .....[9] in payment of the expenses and compensation provided for in this Act exceed the amount of the examination and registration fees collected as herein provided.

The total of warrants issued in any calendar year shall be limited by budget authorization duly prepared and authorized by ..... (proper official or body). Excess of receipts over budgeted authorization shall be held by ..... (proper official) in a special reserve item of the "Professional Engineers' Fund," until the reserve item of the fund amounts to a maximum of $..... Thereafter

7. "Authority" may be replaced by the designation of the proper court or other suitable judicial unit.

8. Insert title of proper State official, and method of authentication and payment.

9. Insert title of proper State official.

the Board shall cause to be made such a reduction of fees, that the return therefrom shall not exceed that necessary for the proper function of the Board.[10]

Section X. Board: Records and Reports

The Board shall keep a record of its proceedings and a register of all applications for registration, which register shall show: (*a*) the name, age, and residence of each applicant; (*b*) the date of the application; (*c*) the place of business of such applicant; (*d*) his educational and other qualifications; (*e*) whether or not an examination was required; (*f*) whether the applicant was rejected; (*g*) whether a certificate of registration was granted; (*h*) the date of the action of the Board; and (*i*) such other information as may be deemed necessary by the Board.

The records of the Board shall be prima facie evidence of the proceedings of the Board set forth therein, and a transcript thereof, duly certified by the secretary of the Board under seal, shall be admissible in evidence with the same force and effect as if the original were produced.

Annually, as of ..... (insert date), the Board shall submit to the Governor a report of its transactions of the preceding year, and shall also transmit to him a complete statement of the receipts and expenditures of the Board, attested, by affidavits of its chairman and its secretary.

Section XI. Roster*

A roster showing the names and places of business of all professional engineers and all land surveyors registered under this act shall be published by the secretary of the Board during the month of ..... of each year. Copies of this roster shall be mailed to each person so registered, placed on file with the Secretary of State, and furnished to the public upon request and to county authorities and to the authorities of the principal cities of the State.

Section XII. General Requirements for Registration

The following shall be considered as minimum evidence satisfactory to the Board that the applicant is qualified for registration as a professional engineer or land surveyor, respectively; to wit:

(1) As a professional engineer:

(*a*) *Engineers—graduation plus experience**

Graduation from an engineering curriculum of four years or more in a school or college which curriculum school or college shall have been approved as of satisfactory standing by the Board or by the National Council of State Boards of Engineering Examiners, or by the National Bureau of Engineering Registration, or by the Engineering Council for Professional Development; and a specific record of an additional four years or more of experience in engineering work of a character satisfactory to the Board, and indicating that the applicant is competent to practice professional engineering (in counting years of experience, the Board at its discretion may give credit, not in excess of one year for satisfactory graduate study in engineering)[11] or

(*b*) *Engineers—examination plus experience*

Successfully passing a written, or written and oral, examination designed to show knowledge and skill approximating that attained through graduation from an approved four-year engineering curriculum; and a specific record of eight years or more of experience in engineering work of a character satisfactory to the Board and indicating that the applicant is competent to practice professional engineering.

(*c*) *Engineers of long-established practice*

A specific record of 12 years or more of lawful practice in professional engineering work of a character satisfactory to the Board and indicating that the applicant is qualified to design or to supervise construction of engineering works and provided applicant is not less than 35 years of age.

(2) As a land surveyor:

(*a*) *Land surveyors—graduation plus experience*

Graduation from a school or college approved by the Board as of satisfactory standing, including the completion of an approved course in surveying; and an additional two years or more of experience in land-surveying work of a character satisfactory to the Board and indicating that the applicant is competent to practice land surveying; or

(*b*) *Land surveyors—examination plus experience*

Successfully passing a written, or written and oral examination in surveying prescribed by the Board; and a specific record of six years or more experience in land-surveying work of a character satisfactory to the Board and indicating that the applicant is competent to practice land surveying.

(*c*) *Land surveyors of long-established practice*

A specific record of ten years or more of lawful practice in land-surveying work of a character satisfactory to the Board and provided applicant is not less than 30 years of age.

Character: No person shall be eligible for registration as a professional engineer, or land surveyor, who is not of good character and reputation.

Teaching credits: In considering the qualifications of applicants, engineering teaching may be construed as engineering experience.

Education credits: The satisfactory completion of each year of an approved curriculum in engineering in a school or college approved as of satisfactory standing by the Board or by the National Council of State Boards of Engineering Examiners, or by the National Bureau of Engineering Registration, or by the Engineering Council for Professional Development, without graduation, shall be considered as equivalent to a year of experience in section XII (1) (*b*). Graduation in a curriculum other than engineering from a college or university of recognized standing may be considered as equivalent to two years of experience in section XII (1) (*b*); provided, however, that no applicant shall receive credit for more than four years of experience because of undergraduate educational qualifications.

Non-practicing applicants: Any person having the necessary qualifications prescribed in this Act to entitle him to registration shall be eligible for such registration although he may not be practicing his profession at the time of making his application.

Section XIII. Applications and Registration Fees

Applications for registration shall be on forms prescribed and furnished by the Board, shall contain statements made under oath, showing the applicant's education and detail summary of his technical work, and shall contain not less than five references, of whom three or more shall be engineers having personal knowledge of his engineering experience.

The registration fee for professional engineers shall be $....., $..... of which shall accompany application, the remaining $..... to be paid upon issuance of certificate. When a certificate of qualification issued by the National Bureau of Engineering Registration is accepted as evidence of qualification, the total fee for registration as professional engineer shall be $.....

The registration fee for land surveyors shall be $....., which shall accompany application.

Should the Board deny the issuance of a certificate of registration to any applicant the initial fee deposited shall be retained as an application fee.[12]

Section XIV. Examinations

When oral or written examinations are required, they shall be held at such time and place as the Board shall determine. If examinations are required on fundamental engineering subjects or land surveying (such as are ordinarily given in college curricula) the applicant shall be permitted to take this part of the professional examination prior to his completion of the requisite years of experience in engineering work or land surveying, and satisfactory passage of this portion of the professional examination by the applicant shall constitute a credit for a period of ten years.

The scope of the examinations and the methods of procedure shall be prescribed by the Board with special reference to the applicant's ability to design and supervise engineering works so as to insure the safety of life, health, and property. Examinations shall be given for the purpose of determining the qualifications of applicants for registration separately in professional engineering and in land surveying. At the discretion of the Board examinees may be permitted to select questions pertinent to their particular specialty in engineering practice. A candidate failing on examination may apply for re-examination at the expiration of six months and will be re-examined without payment of additional fee. Subsequent examination may be granted upon payment of a fee to be determined by the Board.

Section XV. Certificates, Seals*

The Board may issue a certificate of registration, upon payment of registration fee as provided for in this Act, to any applicant who, in the opinion of the Board, has satisfactorily met all the requirements of this Act. In case of a registered engineer, the certificate shall authorize the practice of "professional engineering," and in the case of a registered land surveyor, the certificate shall authorize the practice of "land surveying." Certificates of registration shall show the full name of the registrant, shall have a serial number, and shall be signed

10. The additional clauses are inserted in order to apply closer budgetary control and insure the reduction of fees if and when possible. It is preferable to reduce license fee rather than renewal fee.

11. Clause including various councils was added to insure impartiality and to promote uniformity in approval of curricula and institutions, thus tending toward reciprocity. The action and possible cooperation of the three national bodies mentioned has greater probability of agreement than independent approvals by a large number of State Boards. It might obviate charges of prejudice directed against a State Board because of exclusion of an institution elsewhere approved.

12. It may be advisable in some cases to grant the Board authority, with the approval of the Governor, to increase or decrease the fees for certificates and renewals within certain defined limits, in order to keep the Board self-sustaining, and to meet any objection raised that the passage of the Registration Act would tend to increase taxes.

by the chairman and the secretary of the Board under seal of the Board.

The issuance of a certificate of registration by this Board shall be prima facie evidence that the person named therein is entitled to all the rights and privileges of a registered professional engineer, or of a registered land surveyor, while the said certificate remains unrevoked or unexpired.

Each registrant hereunder may upon registration obtain a seal of the design authorized by the Board, bearing the registrant's name and the legend, "Registered Professional Engineer," or "Registered Land Surveyor." Plans, specifications, plats, and reports approved by a registrant shall be stamped with the said seal[13] when filed with public authorities, during the life of the registrant's certificate, but it shall be unlawful for any one to stamp or seal any documents with said seal after the certificate of the registrant named thereon has expired or has been revoked, unless said certificate shall have been renewed or reissued.[13,14]

Section XVI. Expirations and Renewals

Certificates of registration shall expire on the last day of the month of ..... following their issuance or renewal and shall become invalid on that date unless renewed. It shall be the duty of the secretary of the Board to notify every person registered under this Act, of the date of the expiration of his certificate and the amount of the fee that shall be required for its renewal for one year; such notice shall be mailed at least one month in advance of the date of the expiration of said certificate. Renewal may be effected at any time during the month of ..... by the payment of a fee of $.....[15] The failure on the part of any registrant to renew his certificate annually in the month of ..... as required above shall not deprive such person of the right of renewal, but the fee to be paid for the renewal of a certificate after the month of ..... shall be increased ten per cent for each month or fraction of a month that payment of renewal is delayed; provided, however, that the maximum fee for delayed renewal shall not exceed twice the normal renewal fee.

Section XVII. Practitioners at Time Act Became Effective

At any time within one year after this Act becomes effective, upon due application therefor and the payment of the registration fee of $..... for professional engineers, or $..... for land surveyors, the Board shall issue a certificate of registration, without oral or written examination, to any professional engineer or land surveyor who shall submit evidence under oath satisfactory to the Board that he is of good character, has been a resident of the State of ..... for at least one year immediately preceding the date of his application, and was practicing professional engineering if an engineer, or land surveying if a surveyor, at the time this Act became effective, and has performed work of a character satisfactory to the Board.

After this Act shall have been in effect one year, the Board shall issue certificates of registration only as provided for in section XII or section XIX thereof.

Section XVIII. Public Work

After the first day of ....., 19...., it shall be unlawful for this State, or for any of its political subdivisions, such as a county, city, town, township, or borough to engage in the construction of any public work involving professional engineering, unless the plans and specifications and estimates have been prepared by, and the construction executed under the direct supervision of, a registered professional engineer; provided that nothing in this section shall be held to apply to any public work wherein the contemplated expenditure for the completed project does not exceed $.....

Section XIX. Reciprocity

The Board may, upon application therefor, and the payment of a fee of $....., issue a certificate of registration as a Professional Engineer to any person who holds a certificate of qualification or registration issued to him by proper authority of the National Council of State Boards of Engineering Examiners, or of the National Bureau of Engineering Registration, or of any State or Territory or Possession of the United States, or of any country, provided that the requirements for the registration of professional engineers under which said certificate of qualification or registration was issued do not conflict with the provisions of this Act and are of a standard not lower than that specified in section XII of this Act.

Section XX. Revocations, Reissuance of Certificates, Appeals

The Board shall have the power to revoke the certificate of registration of any registrant who is found guilty of:

(a). The practice of any fraud or deceit in obtaining a certificate of registration;

(b). Any gross negligence, incompetency, or misconduct in the practice of professional engineering or land surveying as a registered professional engineer or land surveyor.

Any person may prefer charges of fraud, deceit, gross negligence, incompetency, or misconduct against any registrant. Such charges shall be in writing, and shall be sworn to by the person making them and shall be filed with the secretary of the Board.

All charges, unless dismissed by the Board as unfounded or trivial, shall be heard by the Board within three months after the date on which they shall have been preferred.

The time and place for said hearing shall be fixed by the Board, and a copy of the charges, together with a notice of the time and place of hearing, shall be personally served on or mailed to the last known address of such registrant, at least 30 days before the date fixed for the hearing. At any hearing, the accused registrant shall have the right to appear personally and by counsel, to cross-examine witnesses appearing against him, and to produce evidence and witnesses in his own defense.

If, after such hearing, three or more members of the Board vote in favor of finding the accused guilty, the Board shall revoke the certificate of registration of such registered professional engineer or land surveyor.

Reissuance of certificates: The Board, for reasons it may deem sufficient, may reissue a certificate of registration to any person whose certificate has been revoked, providing three or more members of the Board vote in favor of such reissuance. A new certificate of registration, to replace any certificate revoked, lost, destroyed, or mutilated, may be issued, subject to the rules of the Board, and a charge of $..... shall be made for such issuance.

Appeals: Any person who shall feel aggrieved by any action of the Board in denying or revoking his certificate of registration may appeal therefrom to the .....[16] and, after full hearing, said court shall make such decree sustaining or reversing the action of the Board as to it may seem just and proper.

Section XXI. Violations, Penalties

Any person who shall practice, or offer to practice, professional engineering or land surveying in this State without being registered in accordance with the provisions of this Act, or any person presenting or attempting to use as his own the certificate of registration or the seal of another, or any person who shall give any false or forged evidence of any kind to the Board or to any member thereof in obtaining a certificate of registration, or any person who shall falsely impersonate any other registrant of like or different name, or any person who shall attempt to use an expired or revoked certificate of registration, or any person who shall violate any of the provisions of this Act, shall be guilty of a misdemeanor, and shall, upon conviction, be sentenced to pay a fine of not less than $....., nor more than $....., or suffer imprisonment for a period not exceeding three months, or both.

It shall be the duty of all duly constituted officers of the law of this State, or any political subdivision thereof, to enforce the provisions of this Act and prosecute any persons violating same. The Attorney General of the State or his assistant shall act as legal adviser of the Board and render such legal assistance as may be necessary in carrying out the provisions of this Act.

Section XXII. Saving Clause*

This Act shall not be construed to prevent or to affect:

(1) *Other professions or trades*

The practice of any other legally recognized profession or trade; or

(2) *Craftsmen*[17]

The activities essential to the normal operation and maintenance of machinery equipment and structures or of craftsmen in the performance of their established functions; or

13. Certain states have made the use of seals optional, except for filing of plans.

14. It is suggested that the Board regulate the exact method of fulfilling the requirement that plans, specifications, plats, and reports shall be stamped. For example, the Board may rule that every sheet be stamped; or that the title or first sheet only need be stamped; or that only contract documents, or documents of record be stamped; and so on.

15. In States where registrants are few, the annual renewal fee may be $5, but in larger States $1 may be sufficient.

16. Insert name of proper court.

17. This clause has been rewritten and relocated from definitions where it occurs in other drafts.

(3) *Non-residents*
The practice of a person not a resident of and having no established place of business in this State, practicing or offering to practice herein the profession of engineering or land surveying, when such practice does not exceed in the aggregate more than 30 days in any calendar year; provided, such person is legally qualified by registration to practice the said profession in his own State or country in which the requirements and qualifications for obtaining a certificate of registration are not lower than those specified in this Act; or

(4) *Recent arrivals in State*
The practice of a person who has recently become a resident, practicing or offering to practice herein the profession of engineering or land surveying, if he shall have filed with the Board an application for a certificate of registration and shall have paid the fee required by this Act; provided, that such a person is legally qualified by registration to practice said profession in his own State or country in which the requirements and qualifications for obtaining a certificate of registration are not lower than those specified in this Act. Such practice shall continue only for such time as the Board requires for consideration of the application for registration; or

(5) *Employees and subordinates*
The work of an employee or a subordinate of a person holding a certificate of registration under this Act, or an employee of a person practicing lawfully under paragraphs (3) or (4) of this section; provided such work is done under the direct responsibility, checking, and supervision of a person holding a certificate of registration under this Act or a person practicing lawfully under paragraphs (3) or (4) of this section; or

(6) *Government officers and employees*
The practice of officers and employees of the Government of the United States while engaged within this State in the practice of the profession of engineering or land surveying, for said Government; or

(7) *Work as a contractor*
The execution of work by a contractor as distinguished from the planning or design thereof or the supervision of the construction of such work as a foreman or superintendent.[18]

(8) Engineering work of a technical character similar to that of a professional engineer when not for hire to the public and when not in public employment.

Section XXIII. Invalid Sections

If any section or sections of this Act shall be declared unconstitutional or invalid, this shall not invalidate any other sections of this Act.

Section XXIV. Repeal of Conflicting Legislation

All laws or parts of laws in conflict with the provisions of this Act shall be, and the same are hereby, repealed.

18. This clause rewritten and relocated. Its intent here is to permit foremen and superintendents to gain experience within the law and without being required to register. Such experience may lead to qualification credits.

Synthetic Materials as Wire Insulation

WINTON PATNODE E. J. FLYNN J. A. WEH

Preceded by a historical outline of the use of synthetic materials for insulating electric conductors, this article reviews in some detail the use of these materials on magnet wire, with particular reference to the recent introduction of the new insulating coating called "Formex" which is a synthetic resin embodying polyvinyl formal and is applied to wires by the floating die method. Comparative tests show this new material to be markedly superior to former enamel insulating coatings.

DESIGNERS of electrical equipment have shown great skill in making the best use, consistent with safety, of the insulating materials available to them, but the extent of their progress in invention and improvement rests jointly upon the ability of the chemist to provide, and the insulation engineer to apply, better and cheaper insulating materials. The successful commercial production of phenol-formaldehyde resins some 30 years ago provided the electrical industry with a new substance that rapidly found wide use in insulation. Today synthetic molded insulation and insulating varnishes have become indispensable. The development of noncombustible, synthetic liquids, waxes, and resins a decade ago added to the safety and reliability of apparatus insulated with them, and they are today widely used throughout the industry. It is only natural, therefore, that chemists and engineers charged with the improvement of insulation have kept their attention on, and have aided in, the increasingly rapid growth of the synthetic resin industry. The alkyd resins, which today are universally used as finishes, grew out of early researches in the field of electrical insulation, and today chemists in the resin industry still look upon electrical insulation as an important field for synthetic resins.

The literature of electrical insulation is voluminous, scattered, and generally descriptive and technical rather than scientific in nature.[1] The purpose of this article is to describe in general the insulation of wire and cable in the electrical manufacturing industry, with particular emphasis upon the recent introduction of synthetic materials.

In the field of high-voltage transmission cable there is today no large use of synthetic resins, although patent literature discloses numerous suggestions that may be

Essential substance of a paper presented before the paint and varnish division of the American Chemical Society, Baltimore, Md., April 3–7, 1939, and published in *Industrial and Engineering Chemistry*, September 1939, issue.

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1. Reference is made to the following articles (numerals referring to numbered list at end of article) which are typical of a larger list of publications dealing with resinous insulation (12, 60, 40, 16, 70, 71, 72, 31, 39, 53, 48, 42, 68, 69, 37, 24, 33, 64, 65, 18, 19, 20, 1, 11, 46, 36, 45, 7, 8, 26, 38, 17, 25, 23, 3, 5, 47, 6, 10, 35) and to a few monographs (66, 75, 56) which are descriptive of the manufacture and use of electrical insulation. Throughout the remainder of the article, numbered references refer to the list at the end.

Figure 1. Typical equipment for applying a baked resinous coating to magnet wire

prophetic. Overhead power lines are insulated from ground and from each other by air and by ceramic suspension insulators. Underground lines are insulated with paper and oil enclosed in a lead sheath. The stranded copper conductor is covered by multiple wrappings of paper tape, and the whole is then evacuated and impregnated with mineral oil. It is unlikely that this combination of paper and oil will immediately be replaced by any known synthetic plastic, owing to the very low dielectric loss and high dielectric strength required. Of the materials available today, polymerized hydrocarbons come closest to having the necessary dielectric properties, but they lack the required physical qualifications. Polystyrene has been used, at least experimentally, in insulating cable joints and terminations,[67,50] and as an aid to the study of manufacture and use of high-voltage cables.[74]

The possibility of replacing the paper tape by a synthetic tape is not so remote. Nowak[50] discusses the employment of derivatives of cellulose for this purpose, as do Hagedorn,[32] and Nowak and Hofmeier.[52] The dielectric properties of ethyl cellulose have been measured and reported by Bass and Goggin[4] and Koch.[41] The replacement of the lead sheath by a synthetic plastic sheath is a future possibility in high-voltage cables, since this has already been done on cables of lower voltage. Pallas[54] compares lead and polyacrylates for cable sheathing. In some cables the viscosity characteristic of the impregnating oil is controlled by dissolved resin, but this application for synthetic resins is not of great importance in the technology of cable manufacture.

In the field of medium-voltage transmission, secondary network, and distribution cable, the application of synthetic materials is a little farther along. Cable of this classification is generally insulated with rubber or with multiple wrappings of varnished cloth tape, and is enclosed within a sheath of lead or a pitch-saturated, weatherproof, textile braid. Synthetic resins have been used as ingredients of the varnished cloth for some time, and although certain advantages accrue from their use, this application has not wrought a major change in the cable industry. The rubber has been replaced to a limited extent by synthetic materials having rubber-like physical properties, but improved chemical properties, particularly as regards resistance to oil, ozone, fire, and general long-time deterioration in use. Cable insulation comprising polychloroprene, alkyd resins, plasticized polyvinyl chloride, organic polysulphide condensation products, polyacrylates, polybutadiene, and similar copolymers, as well as derivatives of cellulose and rubber, are generally of composite construction, employing the different materials to best advantage. Stocklin,[62] Badum,[2] and Roelig[57] discuss the use of Buna as cable insulation, and von Rosenberg[58] describes the properties of a number of rubber-like synthetic plastics. Mabb[43] discusses the temperature limitations of insulation comprising cellulose acetate and plasticized polyvinyl chloride. Hamilton[34] and Pallas[55] discuss the application of plastics to the cable industry, and Fuoss[29] describes the preparation of plasticized polyvinyl chloride for measurement of dielectric properties. Nowak and Hofmeier[51] discuss the limiting properties of plasticized polyvinyl chloride as well as copolymers of butadiene, isobutylene, and acrylic esters. These papers are typical of the work now being pushed at a rapid pace abroad, and of the slower domestic trend toward synthetic materials.

In the field of 110–220-volt distribution wiring and of so-called "code wire," there is considerable activity, and synthetic materials have begun to invade the domain of

rubber compound and saturated textile-braid insulation. In this field the mechanical and chemical requirements may be met by a number of synthetic plastics that are suitable from the dielectric standpoint. At the present time much wire is being insulated with plasticized polyvinyl chloride, under the trade name of Flamenol, which is not only oil- and water-resistant, but also will not support combustion. The insulation is rapidly extruded upon the wire, requires no vulcanization, and may be produced in a variety of colors so essential to complex industrial wiring. Development in this field of low-voltage insulation is proceeding rapidly, and the enormous market in building wire should provide an incentive for large-scale low-cost manufacture of materials.

Insulation of Magnet Wire

A complete discussion of the many problems surrounding the introduction of synthetic materials into any one of the foregoing classifications of wire is a long story in itself. In this article only one classification of wire, magnet wire, is discussed in detail. Magnet wire is here defined as insulated wire generally used in the form of coils for the purpose of interchange of electric and magnetic energy. Although seldom seen, magnet wire is all around us; in many of our homes and automobiles, for example, there are from 10 to 20 devices that depend upon a few turns of wire for their operation. The annual production of magnet wire is over 100,000,000 pounds. It is obvious, therefore, that the insulation of magnet wire is of the greatest importance to the electrical industry. It is the one insulation development that is never finished, for, in spite of the many kinds of insulation used and the continual improvement being made in all of them, the perfect magnet-wire insulation is still to be obtained.

Magnet wire is insulated by wrappings of cotton, silk, artificial silk, asbestos, glass, paper, Cellophane, cellulose acetate, continuous films of baked enamel, sometimes pigmented, and combinations of these materials. Numerous attempts have been made to provide the wire with a flexible insulating film of metal oxide. Descriptions of manufacturing processes, and properties of the wire have been published by Greulich,[30] Nowak,[49] Dunton,[21] Wildy,[73] Fleming,[27] Skinner and Chubb,[61] Doht,[14] Dunton and Muir,[22] Frost,[28] Campredon,[9] Manley,[44] Ditmar,[13] Suzuki and Shimizu,[63] and others and in numerous patents. Irrespective of the type of insulation, it must have certain fundamental properties to be of value, namely, flexibility, extensibility, toughness, temperature stability, and adequate dielectric strength in use.

The insulation must be flexible enough to permit the wire to be wound into coils. It must also be extensible, since the wire is stretched slightly even with the most careful hand winding, and a certain amount of stretch cannot be avoided in machine winding. It should be noted also that sudden jerks sometimes break an otherwise extensible insulation.

Toughness is one of the most important requirements of the insulation because in manufacture and use the wire is subjected to incidental abrasion. The best electrical insulation is of no value if it does not have the physical toughness to resist abuse incurred as it is applied to apparatus. A common device for maintaining tension during winding operates by friction of the wire between two solid blocks. The manufacture of some machines requires that the coils of wire be bent or hammered into place. The operation of many machines of which the wire is a part is accompanied by mechanical vibration.

The insulation must be stable and have long life over a considerable range of temperature. Since most apparatus operates at an elevated temperature, the insulation is subjected to temperature cycles ranging from the low of our northern winters to 40 or 50 degrees centigrade above hot summer temperatures.

Adequate dielectric strength is to be expected of the insulation after it is in place in the machine, and under the conditions of use of the machine. This implies operation over the temperature range noted and also during periods of high humidity. Occasional wetting must also be provided for, and coils are frequently impregnated and coated with a waterproof insulation varnish.

These properties are by no means all that are required of magnet-wire insulation. In special cases it must withstand very high temperatures, strong mineral acids and alkalies, refrigerating liquids, tropical climate, steam, salt water, the solvent action of insulating varnishes and in-

Figure 2. Winding machines such as this not only bend the wire but also stretch it

sulating liquids, iron dust, etc.; in others the dielectric properties must be carefully controlled in order to permit its use in sensitive, tuned, electric circuits.

When considering improvements in magnet-wire insulation, one factor overshadows the others; that factor is the space occupied by the insulation, as provision must be made for this space in the design of machines. As little as 0.001 inch in thickness of the wire insulation, when multiplied by the superposition of turns in a coil, becomes an appreciable volume. The thicker the insulation, the larger the machine; and the cost of the added copper and iron required is often many times the cost of the added insulation. Conversely, sometimes appreciable reductions in the cost of a machine can be made by redesign based upon a reduction of the thickness of the wire insulation. This principle was recognized many years ago, and as early as 1900 attempts were made to replace the bulky textile yarns by thin films of resinous material. One of the first substances applied to wire as a thin film deposited from solution was cellulose acetate, and in 1908 Fleming[27] compared magnet wires insulated with cotton, silk, cellulose acetate, collodion, casein, albumin, and other materials.

Many years ago a thin film of baked drying-oil enamel was found to provide good insulation, and this type of insulation for magnet wire was rapidly developed, until today about 75 per cent of all magnet wire is enameled. The members of the National Electrical Manufacturers Association have agreed upon standard thicknesses of enamel for standard sizes of wire; for the finer sizes, the maximum allowable increase in diameter of the wire is of the order of 0.001 inch or less. In spite of the fact that modern enameled wire is superior to that manufactured in the past, there are many applications where great care must be taken to avoid damaging the film, and much enameled wire is still covered with textile yarn or other wrapping material which provides additional protection.

Consideration of the problem of improving the insulation of magnet wire some years ago, indicated that because of the high dielectric strength and desirable space factor inherent in an enamel film, efforts should be made to improve its mechanical properties. Although minor improvements had been made by the addition of synthetic resins to the oil enamel, major improvements in the physical properties of the film were apparently not to be attained so long as drying oils were the major ingredient. Attention was therefore turned to the production of a wire insulated with a thin film of synthetic resin. After considerable research and development, an insulated wire embodying a thin film of synthetic resin of the polyvinyl acetal type, particularly polyvinyl formal, was produced, which was vastly superior in many respects to wire insulated with conventional enamels.

In undertaking the development of a manufacturing process for magnet wire, there is a choice of methods of manufacture between (1) wrapping a thin film of the resin on wire, (2) extruding the resin directly upon the wire as is done with rubber and other plastic bodies, and (3) coating the wire with a solution of the resin and baking the film by the time-honored process illustrated in figure 1. The first process has the disadvantage of requiring that the ribbon be lapped upon itself in order to get perfect continuity, thus limiting the minimum thickness of insulation that can be applied, to twice the thickness of the ribbon. The practical difficulty and high cost of producing ribbon thin enough to meet the specifications for fine wire makes this process uneconomical except for large wires. The high speed obtainable by the extrusion process is attractive, and this process now is being used for insulating a limited amount of large wire with thick coatings of synthetic materials.

But the extrusion of resin in a uniform, continuous, concentric film in thicknesses of the order of 0.001 inch and less, as required by fine wires, is not easy. Furthermore, with fine wires the high speeds obtainable by the extrusion process are of little advantage, since in the enameling process one man can handle about 100 wires at perhaps 50 feet per minute, making an effective speed per operator of 5,000 feet per minute. The solution process was therefore selected as the most practical method of coating the wire with the polyvinyl formal resin. In the course of the work a further advantage of this process was unexpectedly found when baked films of the resin were discovered to be markedly superior to unbaked films, probably owing to a partial conversion to an insoluble, infusible state.

Solutions of polyvinyl formal resin are very viscous; hence the conventional method of enameling, in which the wire is drawn directly out of the enamel, requires that the resin content of the solution be reduced to a small proportion of the total. Wire can be insulated and has been insulated with polyvinyl acetal type of resins by the conventional method of enameling, but because of the large number of dips and bakes required and the loss of comparatively expensive solvents, improvements in the method were desirable. The well-known processes of applying solutions with the aid of wipers were investigated, and several new wipers were developed, but they were found to be insufficiently stable over long periods of time for the application of the solution uniformly around the wire in accurately measured thickness. The use of rigidly mounted metal dies for applying solutions to wire had been investigated in the General Electric research laboratory many years ago, but because of inherent difficulties had been discarded. It was thus apparent that for practical reasons a new method of applying

Table I. Results of Comparative Tests on Enameled Wire Samples

Sample Number	Increase in Diameter Over Bare Copper	Abrasion Resistance (Number of Turns to Failure)		Compression Resistance	
		Room Temperature	105 Degrees Centigrade	Average Pressure Required for Failure (Pounds)	Average Per Cent Decrease in Thickness
1	0.00245	41	5	790	49
2	0.00165	12	2	960	52
3	0.00290	44	4	1,820	50
4	0.00300	44	8	2,160	50
5	0.00230	46	5	770	38
Formex	0.00285	206	67	5,570	63

very viscous solutions to wire would have to be developed.

The problem was finally solved by the discovery of an entirely new principle of enameling wire—the floating-die principle in which a floating die is maintained concentric with the wire by the wire itself, and applies an accurately measured, concentric, uniform coating of solution around the wire. The usual difficulties experienced in translating any laboratory process to the factory were encountered, and now wire insulated with a film of synthetic resin embodying polyvinyl formal, known by the trademark of Formex, is in large factory production and use.

Comparative Tests on Enamel Coatings

In order to compare Formex wire with other wires insulated with comparable thickness of coating, five samples of number 20 (0.032-inch) heavy enameled wire of different manufacture were purchased on the open market. The National Electrical Manufacturers Association specifications for wire of this size require an increase in diameter from 0.0022 to 0.0030 inch, and the actual increase in diameters of the wires compared is given in table I. These five wires and a Formex wire were examined with the aid of a number of tests designed to evaluate particular properties. These procedures are not standard throughout the industry, but are used by the General Electric laboratories for comparing experimental wires.

The flexibilities of the coatings were compared by observing their behavior when the wires were wound on mandrels of two, five, and ten times the diameter of the wire, at about 40 rpm. The wires were then examined under the microscope, and it was found that none of the samples had cracked during winding.

Extensibility was observed by slowly stretching 100 inches of wire to 110 inches. No cracks were observed in any of the samples. Rapid extensibility was performed by allowing a falling pendulum to act upon a lever which stretched the wire 20 per cent in a fraction of a second. No cracks were observed in the films of any of the wires after this treatment. As mentioned before, winding machines, such as that illustrated in figure 2, not only bend the wire but also stretch it, and in order to observe the effect of an exaggerated treatment of this sort on the six samples of wire, they were all stretched ten per cent in length and then wound on the two-five-ten mandrel. The film on each of the wires except the Formex wire cracked when wound on the mandrel of two times the wire diameter, but not on the others after this treatment. These tests show that enameled wire possesses flexibility and extensibility of a high order, and that control of the amount of stretch given the wire when winding should prevent failures from this source. By comparison, as illustrated in figure 3, Formex wire is in a class by itself.

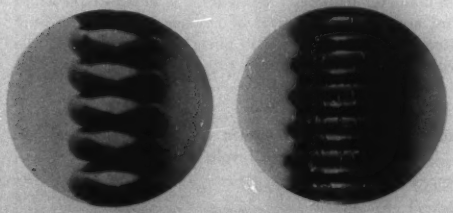

Figure 3. After being stretched at least 20 per cent in length and wound upon its own diameter, the Formex coating showed no signs of cracking (left), the coating of ordinary enameled wire (right) showed severe cracking after having been stretched 10 per cent in length and then wound on a mandrel having twice the diameter of the wire

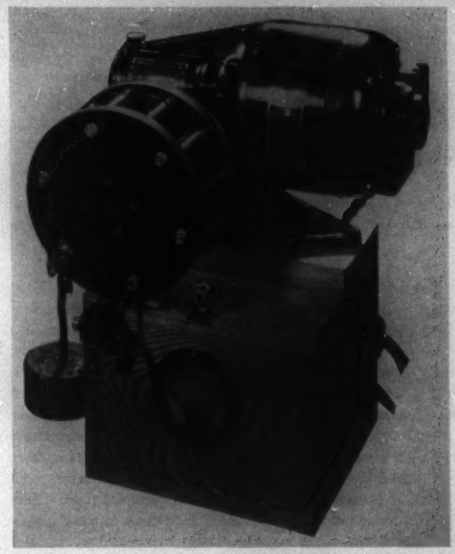

Figure 4. Machine for testing abrasion resistance of enameled wire

In order to compare the resistance of the insulation to abrasion, the six wires were subjected to the abrading action of the machine illustrated in figure 4. One end of the wire to be tested was fastened to the base of the machine, and the other end was brought over the Carboloy spokes of the squirrel-cage drum and was held taut by a weight, thus maintaining a constant pressure of the wire against the spokes. The test consisted in counting the number of revolutions of the drum (which is proportional to the number of rubs given the wire by the Carboloy spokes) required to wear through the film and to produce electrical contact between any one of the rods and the conductor. The results are expressed in number of turns, and the averages of five tests are listed in table I. It may be seen that four of the enameled wires had practically the same abrasion resistance, the fifth is poorer, owing to thinner insulation, and the Formex wire is again in a class by itself.

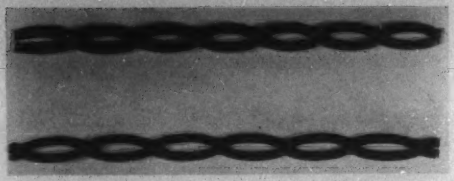

Figure 5. Condition of samples after compression tests, showing the excellent resistance of enameled coatings to compressive stresses

Abrasion and pressure are encountered simultaneously when coils of wire are forced into position in a machine after they have been wound, and a simple test was devised to observe the effect of this operation on the insulation. The wires to be tested were first twisted together into a test piece. Such a twisted pair was then placed between two steel blocks $1^7/_8$ inches long so that seven crossovers were between the blocks. Electrical connection was then made to the wires so that in the event the insulation failed between wires or against either of the steel blocks, a 110-volt lamp was lighted. Pressure was then slowly and uniformly applied to the blocks in a compression testing machine, and the pressure required to rupture the film and complete the electric circuit was recorded. After a failure, the thickness of the flattened portion of the sample was measured, and the per cent change in the thickness of the sample was recorded. Five samples of each wire were so tested. It may be seen from table I and figure 5 that all the wires exhibit excellent resistance to compression, far beyond anything required for ordinary use, and that again the Formex wire is markedly superior to the others.

Tests Simulating Service Conditions

The tests described thus far were designed to compare the effect of mechanical abuse on the insulation, such as is sometimes encountered during assembly of machines. Although they are useful for purposes of comparison, they by no means show that any particular wire can be used successfully in any particular machine. This can be determined only by actual factory trials. Attention now is directed to tests designed to compare the ability of the different insulations to perform their function after they have been wound into the machine.

The purpose of the film on the wire is to insulate the conductor electrically. The quantity and quality of the insulation required depends upon the application, and no single test will serve all applications. However, measurement of dielectric strength is useful, and is generally made. The wires under examination were tested by applying a gradually increasing voltage between two wires twisted together, and recording the voltage at which failure occurred. The samples were tested as received at room temperature and at 105 degrees centigrade, and also after soaking in water overnight (17 hours) at room temperature. The average values of breakdown voltage of five samples are recorded in table II. Note that most of the values for each wire are equally high at room temperature and 105 degrees centigrade, and that, with the exception of sample 2, on which the insulation is thin, the values for the different wires vary only about 30 per cent, which is not greater than the difference between individual samples of the same wire. All the samples lose something by soaking in water, but even this treatment leaves them with sufficiently high dielectric strength for ordinary use. The "annealed" value recorded for Formex wire concerns a property of the film on this wire that is described later in detail. It is well to remember that these tests were made on samples that had been handled very gently, and the values are in no way representative of what might be obtained in practical use.

An illustration of what can happen to enameled wire when it is heated is given in the following test. Samples of the wires were wound on the two-five-ten-diameter mandrel and examined for cracks as in the flexibility test, and none were found. This simulates a winding which appears to be satisfactory by visual examination. The samples were then placed in an oven and heated at 100 degrees centigrade for one-half hour, which simulates the temperature attained by operation of some machines, and again examined, whereupon the coatings of all but the Formex wire and one of the others were found to be badly cracked on the two-diameter mandrel. Now this is an extremely tight turn and would not ordinarily be encountered in winding, so that this is perhaps an unfair test, but it does bring out the fact that mechanical strains set up in the film by winding are sufficient to overcome the tensile strength of the film when hot, and to produce rupture. When samples of the wire were stretched ten per cent in length and then wound, none of them cracked on the five- or ten-diameter mandrel, and all would be considered perfect on visual examination. However, when they were heated to 100 degrees centigrade, all but the Formex wire and one enameled sample showed bad cracks on the five-diameter mandrel, and one cracked on the ten-diameter mandrel. When they were further heated for one-half hour at 150 degrees centigrade, all but the Formex wire cracked on the five-diameter mandrel, and all but the Formex wire and one other cracked on the ten-diameter mandrel. In figure 6 is illustrated Formex wire and the best sample of enameled wire before and after this treatment. This phenomenon appears to be typical of films based on drying-oil enamels, and is one

Table II. Dielectric Breakdown of Enamel Wire Insulation (Kilovolts)

Sample Number	Room Temperature (Dry)	105 Degrees Centigrade (Dry)	Room Temperature (Wet)
1	8.5	5.9	4.4
2	4.1	3.9	2.2
3	9.9	10.5	8.2
4	10.4	10.9	7.8
5	8.9	7.3	5.3
Formex	8.8	7.6	3.2
Formex (annealed)			8.2

that can be very bothersome in difficult windings, requiring that the utmost care be taken in manufacture. Formex wire appears to be immune to this type of failure, as it has never been observed, even in samples stretched more than 20 per cent and then wound on their own diameters.

One of the physical properties that appears to be adversely affected at operating temperatures of apparatus is abrasion resistance. This is important when mechanical vibration from any source sets up vibration of windings and the wires rub together or rub against the confining wall. In order to compare the ability of the wires under examination to resist abrasion at elevated temperature, they were tested on the abrasion machine described, in an oven at 105 degrees centigrade. The average values for five samples are recorded in table I. It may be seen that all the samples are adversely affected, the enamel samples losing from 80 to 90 per cent of their original resistance, and the Formex wire losing two-thirds of its resistance, but in spite of this great loss, it still retains greater resistance to abrasion than the enamel samples had originally.

In any winding there is more or less pressure on the wires under operating conditions owing to expansion and contraction of the parts of the machine. In rotating armatures there is considerable pressure owing to centrifugal force. Although in practice, pressure generally is accompanied by slight vibratory motion and consequent abrasion, it is interesting to observe the flow of the film on the wire at high temperatures in the absence of vibration. For this purpose the device illustrated in figure 7 was employed. Twelve pieces of wire were placed between alternate flat plates as illustrated, so that three inches of wire was under compression between each pair of plates. The wires were straightened to eliminate kinks and to present a continuous line contact to the pressure of the plate. After the samples were assembled in the apparatus, a weight of ten pounds was suspended from the central suspension as illustrated, and the height of the pile of plates and wires was carefully measured with a dial micrometer. The complete assembly was then heated at 125 degrees centigrade for one hour to allow the flow to take place, and the height of the pile was again measured when cold. From the difference in the two measurements the decrease in thickness of the insulation was determined, and was found to be from 10 to 20 per cent, Formex wire showing the greatest decrease of 20 per cent, and sample 2 the lowest of 10 per cent. The other samples were about the same with a range of 14 to 16 per cent.

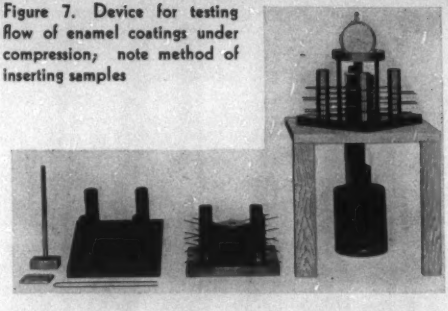

Figure 7. Device for testing flow of enamel coatings under compression; note method of inserting samples

The results of this test are of value for purposes of comparison only. No one yet has succeeded in measuring the actual pressures existing between wires in coils in actual service at operating temperatures, and it is doubtful whether such measurements could be made, or that if made whether windings could be duplicated. It should also be pointed out that in service the stress is not always maintained since the wires can move. For rotating armatures, calculations of centrifugal force can be made and pressures estimated, but so far the only reliable test has been actually to test the wire in position in the machine.

Most electrical machinery falls in the classification of durable goods, and must be built to last for years, so a discussion of insulation is not complete without considering the effects of age. Enameled wire behaves in this respect much as would be expected from its composition. The film becomes harder and more brittle with age, and if not bent will provide adequate insulation for many years. However, the film does become brittle, and provision should be made in the design of the machine for protection against incidental blows or bends that would break this brittle film. In order to compare the ability of the various wires under examination to resist this embrittlement, large coils were placed in ovens at 100, 125, and 150 degrees centigrade, and periodically samples were taken and wound upon the two-five-ten diameter mandrel. Although minor differences were found between the different samples of enameled wire, the major difference was be-

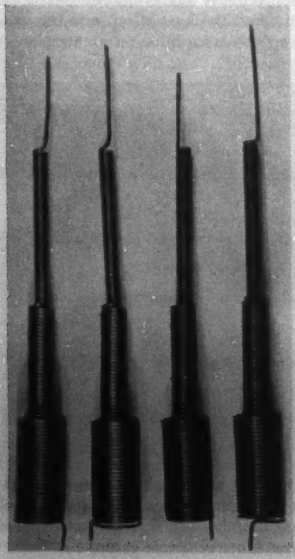

Figure 6. Condition of Formex (left pair) and best enameled samples before (right pair) and after "heat-shock" tests

Figure 8. Condition of samples of enameled wire after having been baked at 125 degrees centigrade for 357 hours and then wound on mandrels having two, five, and ten times the diameter of the wire; the Formex sample is at the left. Although not clearly shown here, four of the enameled samples showed cracking in the ten-diameter coils

tween the enamel wire and the Formex wire, as illustrated in figure 8, which shows samples that had been baked at 125 degrees for 357 hours and then wound. Baking at 100 and 150 degrees centigrade brought out the same difference. The film on the Formex wire retained its flexibility four to ten times longer than those of the enameled wires.

Effect of Varnish Solvents

Thus far we have considered some of the properties of magnet-wire insulation that affect the manufacture and use of apparatus, but there is still one manufacturing operation that, unless properly controlled, can do more to nullify all the work and care put into enameling wire than any other, and that is varnish treatment of the apparatus. The varnish treatment of coils originally was adopted to fill the interstices of textile-insulated wire, to bind the turns of the coil together, and to protect it as well as other insulation in the apparatus from moisture. In late years there has been a trend toward waterproofing insulation before it is assembled in the apparatus, and by using good enameled wire, to eliminate the varnish treatment. This by no means has extended to all lines of apparatus, but is an indication of the trend. In apparatus of this type there is one important reason for varnish treatment after winding, and that is to anchor the turns of the coil so that they cannot become loose through vibration. But whatever the reason, the process is usually the same. The coil or apparatus is soaked in varnish, allowed to drain, and then baked to eliminate the varnish solvents and to "cure" the varnish film. To allow the varnish to impregnate deep into a coil, the soaking must be prolonged, or pressure must be applied; and to drive the solvents out of the deep coil, the baking must be prolonged or vacuum used. The detrimental effect of such varnish treatment on the enamel film was recognized many years ago, and has been discussed by several writers including Frost[28] and Greulick.[30] Although modern enameled wire is superior in many respects to the earlier wire, it is still subject to attack by varnish solvents such as petroleum spirits and coal tar naphtha.

In order to observe the action of varnish solvents on the wires under examination, the following procedure was carried out. Samples of each of the wires were straightened and immersed for a period of three hours at room temperature in (1) petroleum spirits, (2) high-flash naphtha, (3) butanol, and (4) a mixture of equal parts of butanol and high-flash naphtha. The effect on the film was observed by removing each sample from the liquid and immediately subjecting it to controlled abrasion. This was accomplished by drawing the wire under constant pressure at right angles to, and over, a steel wire of 0.010-inch diameter. The pressure on the wire was previously adjusted to a value such that the film of enamel was not damaged when thus abraded before soaking in the solvents. When the soaked samples were so tested, it was found that all of them except the Formex wire were softened enough so that more or less of the film was scraped off (see figure 9). Petroleum spirits had the least effect, and the mixture of butanol and high-flash naphtha, the greatest.

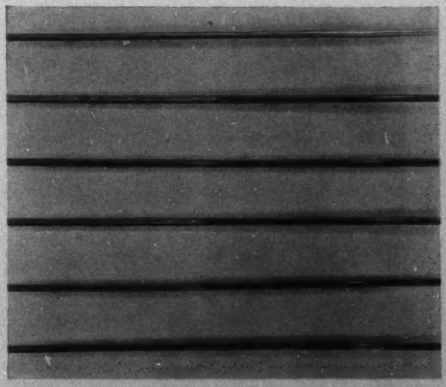

Figure 9. Condition of test samples after having been immersed for three hours at room temperature in a mixture of butanol and high-flash naphtha, and then subjected to an abrasion test (Formex sample at top)

In connection with this test, a phenomenon may be observed that apparently is of importance only with Formex wire. Although the film is not greatly softened by immersion in the commonly used solvents, it is affected under certain conditions in a totally different way. When a sample of Formex wire is bent at room temperature and then immersed in high-flash naphtha, there immediately appears upon the surface of the wire a multitude of fine hairline cracks that may be seen under the microscope. This phenomenon is not specific to high-flash naphtha, but has been observed in connection with many other liquids. If, however, the wire has not been bent, the cracks do not appear. Apparently the stresses produced in the film by bending the wire are great enough to exceed the tensile strength of the material when wet with certain liquids, and in some respects this phenomenon resembles the cracking produced by heat in stressed enamel coatings or that produced by ozone in stressed rubber. It differs from the cracking of enamel and rubber in that the strain decays very rapidly at high temperature, and is consequently easily avoided. This can be accomplished by heating the wire to a sufficiently high temperature and for a long enough time to allow the strain to decay internally, and generally a few minutes at 80 degrees centigrade or above is sufficient (see figure 10). If time enough is allowed, the strains will decay at room temperature, although generally room temperature (25 degrees centigrade) is not high enough to reduce the time much below two weeks.

This heat treatment after winding and before varnish treatment is not necessary if the proper varnish treatment is employed, since the cracks disappear when the varnish is baked. This is not entirely due to filling the cracks with varnish resin, since the phenomenon takes place in the absence of resin. Samples of stressed Formex were dipped in the solvents mentioned, thereby developing surface cracks. They were allowed to dry in the air, and were then baked at 150 degrees centigrade for one-half hour. This treatment resulted in the disappearance of the cracks and the formation of the original smooth glossy surface. The phenomenon of healing by baking has been observed with three commercial insulating varnishes, as well as with solvents, and appears to be general.

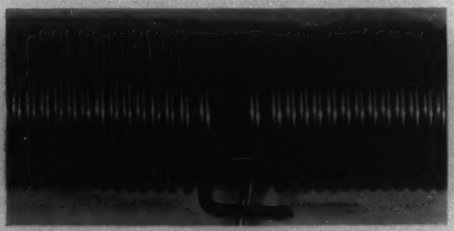

Figure 10. Soaking in high-flash naphtha caused fine surface cracks to appear in the surface of Formex wire (left); these cracks did not appear when the wire (right) previously had been heated for three minutes at 80 degrees centigrade and then soaked in the same liquid

The phenomenon has been studied in relation to the dielectric strength of the insulation. The difference between the dielectric breakdowns for the annealed sample of Formex wire and that for the unannealed sample listed in table II, is probably due to superficial cracking of the surface of the film by water, although the cracks are not visible under the microscope, and water vapor does not produce the same result as liquid water.

When coils were treated with a commercial insulating varnish thinned with benzene and alcohol, the superficial cracks appeared, and were still visible under the microscope after baking at 70 degrees centigrade to evaporate the solvents. The dielectric strength of the insulation, however, even in the presence of these superficial cracks was as high as that of the untreated wire, and after baking at 150 degrees centigrade to cure the resin, the dielectric strength was still higher.

Laboratory tests, such as these described here, give a comprehensive picture of the properties of magnet wire, but must be correlated with factory and field experience in order to judge the importance of each property measured, In the case of enameled wire, we have over 30 years of successful application experience, and have learned how to use it within its limitations. In the case of Formex wire we have properties that are distinctly superior to enamel, which permit changes in manufacturing procedure and redesign of apparatus. In the space of time that Formex wire has been used, some half million pieces of equipment have been wound with it, in some cases as a substitute for enameled wire, or cotton-covered wire; in others, apparatus has been redesigned to take advantage of its superior properties. One of the most interesting examples of its use is in hermetically sealed refrigerator units using the refrigerant known as Freon *F*-12. In this instance it is taking the place of wire previously insulated with more than five times its thickness of cotton.

It is still too soon to say to what extent Formex wire will replace conventional enameled wire. It has been found useful in a wide variety of applications, has permitted advances in manufacturing technique and in the construction of apparatus not hitherto practical, and its use is being extended as rapidly as technical and economic considerations allow. But whatever the outcome, manufacturing and field experience has been so uniformly good that synthetic materials will certainly play an increasingly important part in the field of wire insulation.

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25. Report of Committee D-9 on Electrical Insulating Materials. Proceedings of the American Society for Testing Materials, volume 23, Part 1, 1923, pages 431–47. Also, Electrical Insulating Varnishes, **J. A. Findley, D. Harvey** and **S. T. Rodgers.** *Proceedings* of the American Society for Testing Materials, volume 23, part 2, 1923, pages 423–31.

26. Some Developments in Insulating Materials and Processes in Great Britain, **A. P. M. Fleming.** *India Rubber Journal*, volume 64, 1922, pages 641–4.

27. Cellulose Acetate as Wire Insulation, **R. F. Fleming.** *Engineering News*, volume 59, January 16, 1908, page 59.

28. Treatment of Enamelled Wire Coils, **L. E. Frost.** *Electric Journal*, volume 19, 1922, pages 331–2.

29. Preparation of Polyvinyl Chloride Plastics for Electrical Measurements, **R. M. Fuoss.** *Transactions* of the Electrochemical Society, volume 74, 1938, pages 91–112.

30. Die Einwirkung von Lösungsmitteln und Imprägnierlacken auf Lackdrähte, **E. Grenlich.** *Zeitschrift für Elektrochemie*, volume 44, September 1938, pages 627–36.

31. The Manufacturing of Insulating Varnish, **E. R. Grimsey.** *Paint Manufacture*, volume 4, 1934, pages 44–8.

32. Poured Films for Electrical Insulation, **M. Hagedorn.** *Kunststoffe*, volume 27, 1937, pages 89–90.

33. Plastische Isolationsmaterialien, **A. Hakansson.** *Elektrotechnische Zeitschrift*, volume 31, September 22, 1910, pages 953–8.

34. Application of Some Plastics to the Cable Industry, **M. G. M. Hamilton,** *Transactions* of the Institute of the Plastics Industry (London), volume 7, number 14, 1938, pages 7–15.

35. Plastics and Electrical Insulation, **L. Hartshorn, N. J. L. Megson** and **E. Rushton.** *Journal* of The Institution of Electrical Engineers, volume 83, 1938, pages 474–96.

36. Recent Developments in Electrical Insulating Materials, **L. Hartshorn.** *Journal of Scientific Instruments*, volume 15, 1938, pages 217–22.

37. Insulating Varnishes, **C. O. Harvey.** *Chemistry and Industry Review*, volume 4, April 2, 1926, page 233.

38. Insulation Failure—A Pyroelectric Effect, **J. L. R. Hayden** and **C. P. Steinmetz.** *Electrical World*, volume 80, 1922, pages 865–8.

39. Organic Insulating Materials, **A. C. Hopper.** *Electrician*, volume 96, 1926, pages 258–9.

40. Electrical Insulating Materials, **R. P. Jackson.** *Electric Journal*, volume 16, 1919, pages 326–33.

41. Properties and Uses of Ethylcellulose, **W. Koch.** *Industrial and Engineering Chemistry*, volume 29, June 1937, pages 687–90.

42. What Improvements Does the Engineer Desire in Artificial Plastics? **G. Lucas.** *Kunststoffe*, volume 27, 1937, pages 182–4.

43. Insulating Plastic Tubing, **P. Mabb.** *Plastics* (London), volume 2, 1938, pages 100–02.

44. On the Insulation of Highly Attenuated Wires in Platinum Resistance Thermometers, **J. J. Manley.** *Philosophical Magazine*, series 6, volume 43, 1922, pages 95–6.

45. Insulating Varnishes, **A. R. Matthis.** *Chemical Age* (London), volume 4, 1921, page 501.

46. Waxes, Resins and Asphalts Used in Electrical Apparatus, **L. McCulloch.** *Electric Journal*, volume 35, 1938, pages 281–3.

47. Molecular Physics of Insulation Materials. Examination of the Relation Between Structure and Physical Properties, **F. H. Muller.** *Oel, Kohle, Erdoel, Terr*, volume 13, 1937, pages 591–602.

48. What Improvements Does the Electrical Engineer Desire in Artificial Plastics? **R. Nitsche.** *Kunststoffe*, volume 27, 1937, pages 240–1.

49. Experiences with Artificial Resin Enamels for Insulating Wire, **P. Nowak.** *Kunststoffe*, volume 28, 1938, pages 176–7.

50. Isolierstoffe der Kabelindustrie unter besonderer Berücksichtigung der Cellulosereste, **P. Nowak.** *Angewandte Chemie*, volume 46, September 16, 1933, pages 584–7.

51. Synthetic High Polymers for Use in Making Cables and Wires for Conducting Electricity, **P. Nowak** and **H. Hofmeier.** *Kunststoffe*, volume 28, 1938, pages 54–6.

52. The Development of Cellulose Triacetate Films for Electrical Insulating Purposes, **P. Nowak** and **H. Hofmeier.** *Kunststoffe*, volume 27, 1937, pages 1–2.

53. Insulating Materials. Some Theoretical Chemical Considerations, **W. H. Nuttall.** *Electrician*, volume 87, 1921, pages 484–5.

54. Mäntel aus Kunststoffen für elektrische Kabel, **E. Pallas.** *Korrosion und Metallschutz*, volume 13, March 1937, pages 95–7.

55. Synthetic Materials for the Insulation and Covering of Electrical Conductors and Cables, **E. Pallas.** *Gummi-Zeitung*, volume 52, 1938, pages 55–6.

56. Isolierlacke deren Eigenschaften und Anwendung in der Elektrotechnick, insbesondere im Elektromaschinen und Transformatorenbau, **F. Raskop.** Berlin, M. Krayn, 1938.

57. Technical Properties of Synthetic Rubber, **H. Roelig.** *Zeitschrift* des Vereines Deutscher Ingenieure, volume 82, 1938, pages 139–42.

58. Plastics Having Rubber-Like Properties, **G. von Rosenberg.** *Proceedings* of the Rubber Technology Conference, May 23–25, 1938, pages 450–62.

59. The Application of Styrene to H. T. Cable Systems, **T. R. Scott** and **J. K. Webb.** *Electrical Communication*, part 1, volume 16, October 1937, pages 174–9 and part 3, volume 17, July 1938, pages 88–95.

60. The Story of the Insulations, **C. E. Skinner.** *Electric Journal*, volume 17, 1920, pages 139–45.

61. The Electrolytic Insulation of Aluminum Wire, **C. E. Skinner** and **L. W. Chubb.** *Transactions* of the American Electrochemical Society, volume 26 1914, pages 137–47.

62. The Development of Swelling-Resistant Rubber-Like Materials in Germany, **P. Stocklin.** *Proceedings* of the Rubber Technology Conference, May 23–25, 1938, pages 434–49.

63. The Properties of Enameled Wires for Telephone and Telegraph Use, **M. Suzuki** and **K. Shimizu.** *Researches* of the Electrotechnical Laboratory of Japan, number 104.

64. Insulation Materials, **H. Warren.** *Electrician*, volume 101, 1928, pages 601–03.

65. Insulations. VII: Varnishes, etc., **H. Warren.** *Electrician*, volume 109, 1932, pages 107–09.

66. Electrical Insulating Materials, **H. Warren.** London, Ernest Benn, 1931.

67. A New Joint for Supertension Cables, **J. K. Webb.** *Electrical Times*, volume 86, July 12, 1934, pages 45–6.

68. Chemical Problems in Insulating Varnishes, **H. C. P. Weber.** *Industrial and Engineering Chemistry*, volume 17, January 1925, pages 11–14.

69. Composition and Aging of Insulating Varnishes, **H. C. P. Weber.** *Transactions* of the American Electrochemical Society, volume 44, 1923, pages 53–6.

70. The Problem of Insulation, **J. B. Whitehead.** AIEE Journal, volume 42, June 1923, pages 618–22.

71. Recent Progress in Dielectric Research, **J. B. Whitehead.** Electrical Engineering, volume 55, November 1936, pages 1180–5.

72. Recent Progress in Insulation Research, **J. B. Whitehead.** Electrical Engineering, volume 56, November 1937, pages 1346–52.

73. Insulated Wires, **E. L. Wildy.** *Electrician*, volume 101, November 30, 1928, page 606.

74. Mechanical Uniformity of Paper-Insulated Cables, **K. S. Wyatt, D. L. Smart** and **J. M. Reynar.** AIEE Transactions, volume 57, 1938, (March Section), pages 141–54.

75. Elektrotechnischer Isolierstoffe, **R. Vieweg.** Berlin, J. Springer, 1937.

News
Of Institute and Related Activities

Middle Eastern District Meeting in Scranton, Pa., October 11–13

ARRANGEMENTS are being completed for the AIEE Middle Eastern District meeting and Student Branch convention to be held in Scranton, Pa., October 11–13. Headquarters for the meeting will be at Hotel Casey. The local committees have arranged an attractive and diversified technical program of five morning and afternoon sessions. A testimonial luncheon in honor of Doctor C. F. Scott, AIEE past-president and founder of Student Branches, is being sponsored by the Branches, and separate meetings of Branch counselors and Branch chairmen have been arranged. Among interesting inspection trips scheduled is one through anthracite-coal mines. Entertainment and social gatherings have been arranged for the evenings, with a special program for women guests, who are urged to attend the meeting.

Host for the District meeting is the Lehigh Valley Section, which comprises northeastern Pennsylvania and a small section of New Jersey. Scranton, selected by the Section as host city, is situated in the heart of the anthracite-coal region, surrounded by the picturesque Moosic mountains of the Appalachian range. Called "the electric city," it is the third largest city in Pennsylvania, with a population of 145,000 and a local trade density of 300,000, and is easily accessible by train or car from all parts of the District, being served by four railroads and two major highways. Besides being the metropolis of the anthracite-coal industry, the city has other diversified industries, including silk, moulded products, and textiles, and contains the home office of the International Correspondence Schools, largest institution of the kind in the world.

Program for Women Guests

Wednesday, October 11

Morning	Registration, Hotel Casey
1:00 p.m.	Luncheon, The Scranton Club
2:00 p.m.	Reading and musical program, The Scranton Club
8:30 p.m.	Informal get-together and entertainment (details at Registration Desk)

Thursday, October 12

9:30 a.m.	Leave headquarters hotel for The Scranton Country Club—golf, tennis, games, bridge
12:30 p.m.	Luncheon, The Scranton Country Club
2:00 p.m.	Scenic tour (on return trip will stop at The Scranton Country Club; details will be announced.)
6:30 p.m.	Informal dinner and dance, Hotel Casey

Friday, October 13

This day has been purposely left open in the belief that some of the women guests would like to join their husbands in the inspection trip to the Marvine anthracite coal mines (see schedule).

Inspection Trips

Six inspection trips, three on Wednesday, October 11, and three on Friday, October 13, have been arranged. To assist the committee in planning transportation, members are requested to make definite arrangements at the registration desk, where they will find a schedule of the times at which trips leave from headquarters. The following trips have been planned:

Wednesday, October 11

1. *Marvine anthracite-coal mines of the Hudson Coal Company.* The trip through the mines includes inspection of the company's immense underground pumping project. Inasmuch as operations at this mine involve handling an average of some 27 tons of water for each ton of coal shipped to market, pumping constitutes a very important problem. As an indication of the equipment involved, it is noteworthy that eight pumps, aggregating 32,000 gallons per minute in capacity and driven by a total of 3,200 horsepower in 25-cycle motors, occupy one underground gallery 181 feet long, 22 feet wide, and 30 feet high, while related switchboard and control equipment occupies an adjacent gallery 40 by 12 by 17 feet in size. This trip will be repeated on Friday.

2. *International Correspondence Schools, Scranton.* Largest correspondence school in the world.

3. *Wallenpaupack hydroelectric plant of the Pennsylvania Power and Light Company, Hawley, Pa.* This station has a capacity of 40,000 kw, in two 20,000-kw units. The reservoir, when full, forms a lake 13 miles long and a mile wide, containing 7,400,000 cubic feet of water. The pipe-line from lake to generating plant is 3.5 miles long and 14 feet in diameter. This trip includes a drive of about 35 miles through the woodlands of northeastern Pennsylvania.

Friday, October 13

1. *Hazard insulated-wire works of the Okonite Company, Wilkes-Barre, Pa.* Members will be welcomed by the staff of the company and conducted through the plant.

2. *Stanton steam plant.* Located about 4 miles above Pittston on the Susquehanna River and about 15 miles from Scranton, the Stanton plant, capacity 100,000 kw, is the largest plant in this section of the country burning anthracite coal to generate electricity. Members of the staff will conduct a tour of the entire plant, from the point at which anthracite coal is unloaded, a car at an operation, from the railroad's gondola, to the boiler plant where it is transformed into steam, the steam generators, and the electrical switchyard.

3. *Marvine anthracite-coal mines of the Hudson Coal Company.* Same as Wednesday trip.

Entertainment and Sports

A stag smoker will be held on Wednesday evening at the Hotel Casey. Diversified entertainment will be followed by a buffet supper. Tickets $1.00.

On Thursday, October 12, an informal dinner will be served at 6:30 p.m. at Hotel Casey. Talks will be given by national and District officers and by a guest speaker, after which there will be dancing; tickets $1.50 per person.

Arrangements have been made with the Scranton Country Club for golf, and the Scranton Tennis Club for tennis. Those desiring to play golf should make inquiry at the registration desk Wednesday morning, and watch for announcements by the committee in charge.

Women's Program

A special invitation is extended to women to attend the District meeting with their husbands. Particular attention has been given to the program of activities (see accompanying schedule). To assist the committee in arranging for transportation and luncheons, guests are requested to register

Hotel Rates in Scranton, Pa.

Hotel	Location	Single Rooms: Running Water	Single Rooms: Bath	Double Rooms: Running Water	Double Rooms: Bath
Casey*	Lackawanna and Adams Avenues	$2.50	$3.00–5.00	$4.00	$5.00–8.00†
Jermyn	Wyoming Avenue and Spruce Street	2.00, 2.50	2.50–3.50	3.00, 3.50	4.00–6.00
Marquette	416 Adams Avenue	1.25, 1.50	2.00	2.00, 2.50	3.00
Holland	408 Adams Avenue	1.50	2.00	2.00, 2.50†	3.00, 3.50†
YMCA‡	Washington Avenue and Mulberry Street	1.25	1.50		

* Meeting headquarters. Suites are available at Hotel Casey at $7.50–10.00 for single occupancy; $9.00–12.00 for double occupancy. Some can accommodate from four to eight people, at $1.50 daily per person for each additional occupant.

† Some double rooms with twin beds.

‡ Rooms without running water: single $1.00; double $1.50.

In all cases, individual guests occupying double room with bath will be charged full double-room rate.

for attendance at the events on the program at least three hours before time scheduled.

HOTELS AND REGISTRATION

Members should make room reservations by writing directly to the hotel of their preference. Rates at the headquarters hotel and others are listed in the accompanying table. All the hotels listed are within four or five blocks of the headquarters hotel.

Members of the District who plan to attend the meeting should register in advance by returning the addressed advance-registration card which they will receive by mail. This will be helpful to the registration committee, permit badges to be prepared in advance, and reduce the work necessary on the opening day. A minimum registration fee of $2.00 will be charged all nonmembers except Enrolled Students and the immediate families of members.

COMMITTEES

District meeting: I. Melville Stein, H. A. Dambly, E. F. DeTurk, A. G. Ennis, W. A. Furst, J. W. Mills, H. S. Phelps, J. E. Treweek, E. F. Weaver.

General: E. F. DeTurk, *chairman;* J. L. Beaver, J. G. Charest, N. S. Hibshman, W. H. Lesser, J. W. Mills, G. E. Northup, M. O'Toole, and E. F. Weaver.

Meetings and papers: J. G. Charest, *chairman;* E. Bell, G. M. Keenan, W. J. Kistler, J. W. Mills.

Student activities: N. S. Hibshman, *chairman;* W. H. Formhals, G. A. Irland, E. E. Kimberly, F. W. Smith, W. M. Young.

Inspection and transportation: W. H. Lesser, *chairman;* R. C. Cox, W. J. D. Geary, L. H. James, F. W. Jennings, C. H. McKnight.

Hotels and registration: J. W. Mills, *chairman;* D. J. Connell, F. C. Pethick, W. A. Thomas.

Publicity and attendance: G. E. Northup, *chairman;* W. A. Everson, W. H. Formhals, W. J. Kistler, P. Markarian, R. Moore, A. B. Platt, J. A. Strelzoff, F. A. Weaver.

Entertainment: M. O'Toole, *chairman;* W. E. Connor, R. C. Cox, W. J. D. Geary, G. E. Northup, W. Selple.

Finance: E. F. Weaver, *chairman;* O. A. Griesmer, W. H. Lesser, J. E. Treweek.

Ladies: Mrs. G. E. Northup, *chairman;* Mrs. J. G. Charest, Mrs. A. B. Platt, Mrs. J. A. Strelzoff, Mrs. E. F. Weaver.

Tentative Program

Advance copies of papers will be made available as papers are approved. If ordered by mail, price ten cents per copy; if purchased at Institute headquarters or at the meeting, price five cents per copy. The announcement of the meeting to be sent to members within the District and nearby territory will carry an order form for those who wish to order advance copies of papers.

Discussions to be considered for publication should be typewritten (double-spaced) and submitted in triplicate to C. S. Rich, secretary, technical program committee, AIEE headquarters, 33 West 39th Street, New York, N. Y., on or before October 27, 1939. Discussion of informal addresses and papers need not be submitted.

Wednesday, October 11

9:00 a.m. Registration

10:30 a.m. Mining

APPLICATION OF POWER IN THE ANTHRACITE COAL INDUSTRY. W. H. Lesser, Pierce Management

MERCURY ARC RECTIFIERS IN THE COAL MINING INDUSTRY. D. H. Renshaw, Westinghouse Electric and Manufacturing Company

NEW TYPE MINE LOCOMOTIVE. H. F. Flowers, Differential Steel Car Company

Formal meeting of AIEE standards co-ordinating committee 4

2:00 p.m. Standards

OPERATING CONDITIONS AFFECTING ELECTRICAL APPARATUS MET WITH IN THE STEEL INDUSTRY. O. A. Caldwell, Westinghouse Electric and Manufacturing Company

APPLICATION OF CLASS B INSULATION TO DIRECT CURRENT MOTORS IN HEAVY DUTY SERVICE. F. A. Compton, Jr., General Electric Company

GUIDE FOR SELECTION OF DISTRIBUTION TRANSFORMER SIZE AS DETERMINED BY LOAD CYCLE REQUIREMENTS. M. F. Beavers, General Electric Company

TEMPERATURE RISE OF ELECTRICAL APPARATUS AS AFFECTED BY RADIATION. G. W. Penney, Westinghouse Electric and Manufacturing Company

RÉSUMÉ OF WORK OF THE STANDARDS COMMITTEE ON REVISING AIEE STANDARD NO. 1. P. L. Alger, chairman, AIEE co-ordinating committee 4

Afternoon. Inspection trips

8:30 p.m. Stag smoker

Thursday, October 12

9:30 a.m. Power Transmission and Distribution

POWER SUPPLY FOR SUBURBAN AREAS. R. A. Hentz and J. A. Thielman, Philadelphia Electric Company

PROTECTOR TUBES FOR POWER SYSTEMS. H. A. Peterson and W. J. Rudge, General Electric Company, and A. C. Monteith and L. R. Ludwig, Westinghouse Electric and Manufacturing Company

LIGHTNING INVESTIGATION ON A 220-KV SYSTEM III. Edgar Bell, Pennsylvania Power and Light Company

SOME RECENT DEVELOPMENTS IN IMPULSE VOLTAGE TESTING. C. M. Foust and N. Rohats, General Electric Company

9:30 a.m. Student Branch Counselors' Conference

Professor E. E. Kimberly, Ohio State University, chairman Student Branch activities, District 2, presiding

9:30 a.m. Student Branch Officers and Delegates Conference

W. M. Platt, Lafayette '40, chairman
R. B. Schnure, Bucknell '40, secretary

12:00 m. Testimonial Luncheon

Sponsored by the Student Branches in honor of Doctor Charles F. Scott, past-president AIEE, and founder of the Student Branches of the Institute.

A. S. Mickley, Lehigh '40, presiding

Professor F. C. Caldwell, Ohio State University

Doctor Charles F. Scott

Dean William M. Young, Ohio University

2:30 p.m. Meters, Relays, and Protection

NEW DEVELOPMENTS IN CURRENT TRANSFORMER DESIGN. G. Camilli, General Electric Company

CARRIER CURRENT CONTROL. A. M. Trogner, Line Material Company

DISTRIBUTION LINE SECTIONALIZING. R. E. Neidig, Metropolitan Edison Company

OILLESS CIRCUIT BREAKERS. D. C. Prince, General Electric Company

6:30 p.m. Dinner (strictly informal)

Elmer F. DeTurk, toastmaster

Speakers (reserved as a surprise)

9:30 p.m. Dancing

Friday, October 13

9:30 a.m. Electrical Apparatus

TRENDS IN HIGH-VOLTAGE PORCELAIN BUSHING DEVELOPMENT. T. F. Brandt, Ohio Brass Company

TRANSFORMER PROTECTION AND OPERATION. J. B. Hodtum, Allis-Chalmers Manufacturing Company

ADJUSTABLE SPEED A-C MOTOR. Howard W. Edmunds, Crocker-Wheeler Electric Manufacturing Company

THEORY AND DESIGN OF NEMA RESISTORS FOR MOTOR STARTING AND SPEED CONTROL. G. C. Armstrong, Westinghouse Electric and Manufacturing Company

Afternoon. Inspection Trips

Lamme Medal Nominations Due December 1

Attention is called again to the opportunity open to any member of the Institute to submit nominations for the 1939 AIEE Lamme Medal. All nominations must be received not later than December 1 (for further particulars, see ELECTRICAL ENGINEERING for June 1939, page 265). The 1938 Lamme Medal was awarded to Marion A. Savage, designing engineer, General Electric Company, Schenectady, N. Y.

ASME and Cornell Honor Thurston

The hundredth anniversary of the birth of Robert Henry Thurston, pioneer in engineering education and first president of the American Society of Mechanical Engineers, will be celebrated by Cornell University and the ASME with ceremonies at Ithaca, N. Y., October 25, 1939. The day's program will include an academic procession, memorial ceremony, and an exhibit of Thurston's publications and laboratory apparatus. Delegates from American and Canadian engineering schools and from technical and academic societies, and alumni of Stevens Institute of Technology and Cornell University from the classes of Thurston's time, have been invited to participate in the celebration.

Great Lakes District Meeting in Minneapolis, Minn., September 27–29

THE AIEE Great Lakes District extends a cordial invitation to attend the meeting in Minneapolis, September 27–29, 1939. Headquarters will be in the Hotel Nicollet. An excellent technical program, supplemented by interesting inspection trips and entertainment, is offered for members, their families, and friends of the Institute. Student members will find a special program arranged for them, with members of their own group offering papers for discussion.

During the period of the meeting the District executive committee and the District committee on student activities will hold their respective annual business meeting and conference.

Entertainment and Sports

A variety of entertainment, including a luncheon, sightseeing tours, and dinners has been arranged for the meeting. On Wednesday, September 27, a joint luncheon with the Minneapolis Engineers Club and the St. Paul Engineers Society will be held at the Hotel Nicollet, tickets 85 cents each. In the afternoon a sightseeing tour through Minneapolis, St. Paul, and the vicinity is planned, tickets $1.25 each. At 7 p.m. a dinner will be held at the Minneapolis Automobile Club, tickets $1.50 each.

On Thursday afternoon arrangements will be made to visit the new modern hydraulic laboratory of the University of Minnesota, tickets 25 cents each. In the evening at 7 o'clock a dinner dance will be held at the Hotel Nicollet—tickets $2.00 each. The gathering will be addressed by Doctor Phillips Thomas.

On Friday, September 29, opportunity will be given to visit any of the industrial, educational, and scenic points of interest in and around the Twin Cities, such as: The Electric Machinery Company, The Minneapolis - Honeywell Heat Regulator Company, the University of Minnesota, the generating plants of the Northern States Power Company, the Minnesota Mining and Manufacturing Company, Fort Snelling, Mendota, and others, tickets 50 cents each. Booklets containing tickets for all the trips mentioned will be available at the registration desk for $5.00.

No golf tournament has been scheduled, but arrangements to play on the University of Minnesota course, or on any of the beautiful public or private courses in the Twin Cities will be made by the entertainment committee upon request.

On Saturday, September 30, the famous "Golden Gopher" football team plays the University of Arizona team. This is the first game of the 1939 season. Tickets are $2.20 or $1.10 per seat, depending upon location. Reservations may be made directly with the football ticket manager, University of Minnesota, Minneapolis.

Student Branch Convention

A technical session and a business session have been planned specifically for student members. All trips and entertainment features of the program are open to students. For further information student members should contact Professor J. H. Kuhlmann, counselor of the University of Minnesota Branch, at the electrical-engineering department, University of Minnesota, Minneapolis.

Hotels and Registration

Members should make room reservations by writing directly to the hotel of their preference. For convenience the rates of the headquarters hotel, Hotel Nicollet, as well as the rates of other hotels are listed in the accompanying table.

Members of the District who plan to attend the meeting should register in advance by returning the addressed, advance-registration card which they will receive by mail. This will be helpful to the registration committee, permit badges to be prepared in advance, and reduce the work necessary on the opening day. A minimum registration fee of $2.00 will be charged all nonmembers except Enrolled Students and the immediate families of members.

Committees

District Meeting: A. H. Lovell, District vice-president; A. G. Dewars, District secretary;

Program for Women Guests

Wednesday, September 27

Morning	Registration
Noon	Visit and uncheon, Minneapolis Art Institute. Tickets 75 cents each
Afternoon	Sightseeing trip, for members, their families, and guests
Evening	Dinner at Minneapolis Automobile Club, Bloomington-on-the-Minnesota

Thursday, September 28

Morning	Leave Nicollet Hotel for trip to Stillwater, Minnesota. Luncheon and cards at Lowell Inn, returning to Minneapolis about 3 p.m. Luncheon tickets, 85 cents each
Evening	Dinner-Dance at Hotel Nicollet

Friday, September 29

Open for sightseeing trips and other entertainment to be announced on first day of meeting.

Women guests who desire to play golf will find numerous excellent courses, both public and private, at their disposal. Necessary arrangements will be made upon request to the entertainment committee.

Hotel Rates in Minneapolis, Minn.

Hotels	Location	Without Bath Single	Without Bath Double	With Bath Single	With Bath Double
Nicollet*	Nicollet at Washington			$3.00 up	$4.50 up
Andrews	Hennepin at Fourth Street	$1.50 up	$2.50 up	2.50 up	3.50 up
Curtis	Tenth at Fourth Avenue South			2.00 up	3.00 up
Dyckman	27 South Sixth Street			2.00 up	3.00 up
Leamington	Tenth at Third Avenue South			2.50 up	3.50 up
Radisson	45 South Seventh Street	2.00 up	3.50 up	3.00 up	4.50 up

* Meeting headquarters

Tentative Program

Advance copies of papers will be made available as papers are approved. If ordered by mail, price ten cents per copy; if purchased at Institute headquarters or at the meeting, price five cents per copy. The announcement of the meeting to be sent to members within the District and nearby territory will carry an order form for those who wish to order advance copies of papers.

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Wednesday, September 27

8:00 a.m. Registration, mezzanine floor

9:30 a.m. General Meeting

Announcements: **A. H. Lovell**, vice-president Great Lakes District, AIEE

Address of Welcome: **Governor Harold E. Stassen**

10:15 a.m. Communication and Research

LOAD-RATING THEORY FOR MULTICHANNEL AMPLIFIERS. **B. D. Holbrook** and **J. T. Dixon**, Bell Telephone Laboratories, Inc.

EMERGENCY RADIO IN THE TELEPHONE BUSINESS. **R. E. Willey**, Northwestern Bell Telephone Company

IMPORTANCE OF GAS IN ELECTRODES FOR THE GLOW-TO-ARC TRANSITION. **F. A. Maxfield, H. R. Hegbar**, and **J. R. Eaton**, The University of Wisconsin

CAUSES OF CORROSION OF FINE COPPER WIRES CARRYING A POTENTIAL. **H. N. Stephens** and **G. B. Gehrenbeck**, Minnesota Mining and Manufacturing Company

10:15 a.m. Electrical Machinery and Transportation

DYNAMIC CHARACTERISTICS OF A SINGLE-PHASE INDUCTION MOTOR. **E. B. Kurtz**, University of Iowa

CO-ORDINATION OF THE CONTROL OF SYNCHRONOUS-MACHINE EXCITATION. **L. L. Fountain**, Westinghouse Electric and Manufacturing Company, **E. F. Dissmeyer** and **J. A. Elzi**, Commonwealth and Southern Corporation

POLARIZED FIELD FREQUENCY CONTROL OF SYNCHRONOUS MOTORS. **E. W. Swanson**, Electric Machinery Manufacturing Company

MODERNIZATION OF A TRANSIT SYSTEM. FACTORS THAT DETERMINE THE CHOICE OF VEHICLE. **George L. Hoard**, University of Washington

12:15 p.m. Joint Luncheon With Minneapolis Engineers Club and St. Paul Engineers Society

2:30 p.m. Tour of Minneapolis, St. Paul, and vicinity

7:00 p.m. Dinner at the Country House of the Automobile Club of Minneapolis at Bloomington-on-the-Minnesota

Thursday, September 28

9:30 a.m. Selected Subjects and Measurements

AN UNSTABLE NONLINEAR CIRCUIT. **C. M. Summers**, General Electric Company

PROTECTOR TUBES FOR POWER SYSTEMS. **H. A. Peterson** and **W. J. Rudge**, General Electric Company, and **A. C. Monteith** and **L. R. Ludwig**, Westinghouse Electric and Manufacturing Company

SOME RECENT DEVELOPMENTS IN IMPULSE-VOLTAGE TESTING. **C. M. Foust** and **N. Rohats**, General Electric Company

ELECTRONIC MEASUREMENT OF SURGE-CREST VOLTAGES. **J. M. Bryant** and **M. Newman**, University of Minnesota

MEASUREMENT OF VERY SHORT TIME LAGS. **J. M. Bryant** and **M. Newman**, University of Minnesota

9:30 a.m. Student Session

Papers from members of the Student Branches in the Great Lakes District area will be presented

12:15 p.m. Luncheon, Hotel Nicollet

1:30 p.m. Business Session: Great Lakes District Committee on Student Activities

Chairman **Ben S. Willis**, Iowa State College, presiding

3:30 p.m. Inspection Trip to Hydraulic Laboratory, University of Minnesota

7:00 p.m. Dinner, Hotel Nicollet

Address, "Developments in Research," accompanied by demonstrations, by Doctor **Phillips Thomas**, research engineer, Westinghouse Electric and Manufacturing Company

Dancing

Friday, September 29

9:30 a.m. Power Transmission and Distribution

RATIO-DIFFERENTIAL PROTECTION OF TRANSMISSION LINES. **R. M. Smith** and **M. A. Bostwick**, Westinghouse Electric and Manufacturing Company

ARC-FURNACE LOADS ON LONG TRANSMISSION LINES. **T. G. LeClair**, Commonwealth Edison Company

ANALYSIS OF FACTORS WHICH INFLUENCE THE APPLICATION, OPERATION, AND DESIGN OF SHUNT-CAPACITOR EQUIPMENTS SWITCHED IN LARGE BANKS. **J. W. Butler**, General Electric Company

CYCLIC LOADING OF SUBWAY-TYPE DISTRIBUTION TRANSFORMER. **O. W. Muckenhirn**, University of Minnesota, and **H. G. Zambell**, Allis-Chalmers Manufacturing Company

VAULTS FOR A-C SECONDARY NETWORKS. **J. S. Parsons**, Westinghouse Electric and Manufacturing Company

12:15 p.m. Luncheon

1:30 p.m. Inspection Trips

1:30 p.m. Annual Meeting of Executive Committee, Great Lakes District

Vice-President **A. H. Lovell**, presiding

H. W. Anderson, J. H. Bowman, J. H. Bryant, R. E. Burlingame, J. A. Fitts, E. H. Hagensick, C. H. Nelson.

General: C. H. Nelson, *chairman;* R. E. Burlingame, J. M. Bryant, A. G. Dewars, J. B. Garthus, E. H. Hagensick, Truman Hibbard, J. H Kuhlmann, H. W. Meyer, Mrs. H. W. Meyer.

Meetings and papers: I. B. Garthus, *chairman;* P. G. Bowman, E. N. Clark, W. H. Gille, H. E. Hartig, C. C. Nelson.

Entertainment: H. W. Meyer, *chairman;* Andrew Nelson, M. E. Todd.

Transportation and inspection: R. G. Hagensick, *chairman;* J. M. Bryant, R. R. Herrmann.

Finance: Truman Hibbard, *chairman;* R. F. Pack, H. J. Pierce.

Publicity: A. G. Dewars, *chairman;* Oscar Gaarden, E. W. Johnson.

Student sessions: J. H. Kuhlmann, *chairman;* O. W. Muckenhirn, H. A. Sanderson.

Hotels and registration: R. E. Burlingame, *chairman;* W. Endicott, W. C. Walsh.

Women's entertainment: Mrs. H. W. Meyer, *chairman;* Mrs. J. H. Kuhlmann, Mrs. Andrew Nelson, Mrs. C. H. Nelson, Mrs. M. E. Todd.

Connecticut Section to Honor Charles F. Scott

For the first meeting of the year 1939–40, the AIEE Connecticut Section will hold a testimonial dinner to Charles Felton Scott on his 75th birthday. The meeting will be held at the New Haven Lawn Club at 7:00 p.m., Tuesday, September 19, 1939. Approximately 20 leading engineering and scientific societies with which Professor Scott has been closely associated in his long career are co-operating with the Connecticut Section to honor him on this occasion.

Professor Scott was president of AIEE in 1902–03 and was recipient of the Edison Medal in 1929. He was prime mover in the organization of the Connecticut Section and was its first chairman. He has been a leader in the field of engineering and engineering education, having been associated with Westinghouse Electric and Manufacturing Company from 1888 to 1911, and professor of electrical engineering at Yale University from 1911 to 1933. His interest in Institute and scientific affairs is undiminished today and he directs a large proportion of his time and energy to engineering education. He is very active in the Society for the Promotion of Engineering Education and the Engineering Council for Professional Development, and is president of the National Council of State Boards of Engineering Examiners.

The principal speaker of the evening will be AIEE President F. Malcolm Farmer. Invited guests include the board of directors, past-presidents, and all members of AIEE, and members of the many other engineering and scientific societies with which Professor Scott has been associated. Many of his former students will be present. Russell G. Warner, United Illuminating Company, New Haven, Conn., is chairman of the general committee in charge of the dinner.

AIEE Directors Meet at New York World's Fair

THE regular meeting of the board of directors of the AIEE was held in the Consolidated Edison Company building at the New York World's Fair August 4, 1939.

Present: *President*—F. Malcolm Farmer, New York, N. Y. *Past Presidents*—John C. Parker, New York, N. Y.; W. H. Harrison, New York, N. Y. *Vice-Presidents*—T. F. Barton, New York, N. Y.; F. C. Bolton, College Station, Texas; Chester L. Dawes, Cambridge, Mass.; E. E. George, Chattanooga, Tenn.; C. T. Sinclair, Pittsburgh, Pa.; J. M. Thomson, Toronto, Ont. *Directors*—C. R. Beardsley, New York, N. Y.; Mark Eldredge, Memphis, Tenn.; L. R. Mapes, Chicago, Ill.; K. B. McEachron, Pittsfield, Mass.; H. S. Osborne, New York, N. Y.; C. A. Powel, East Pittsburgh, Pa.; D. C. Prince, Philadelphia, Pa.; R. W. Sorensen, Pasadena, Calif. *National Treasurer*—W. I. Slichter, New York, N. Y. *National Secretary*—H. H. Henline, New York, N. Y. Present by invitation: C. R. Jones, New York, N. Y., *former director*.

Minutes of the meeting of the board of directors held June 29, 1939, were approved.

Report was presented and approved of recommendations adopted by the board of examiners at a meeting held July 20, 1939. Upon recommendation of the board of examiners, the following actions were taken: 12 applicants were transferred to the grade of Fellow; 58 applicants were transferred, 13 elected, and 3 re-elected to the grade of Member; 97 applicants elected and 11 re-elected to the grade of Associate; 11 Students were enrolled.

The finance committee reported disbursements in July amounting to $35,956.20, and the report was approved.

Upon nomination by the standards committee, it was voted that K. B. McEachron, A. C. Monteith, and H. R. Stewart be appointed Institute representatives on the sectional committee on lightning arresters, C62, now being organized under ASA procedure.

Announcement was made of the appointment by the president of Institute committees for the administrative year beginning August 1, 1939 (list published elsewhere in this issue).

As required by the bylaws of the Edison Medal committee, the board confirmed the following appointments by the president: W. B. Kouwenhoven, F. V. Magalhaes, and L. W. W. Morrow as members of the committee for the five-year term beginning August 1, 1939, and of L. W. W. Morrow as chairman for the year 1939–40. The board elected from its own membership to serve as members of the committee for the term of two years beginning August 1, C. R. Beardsley, Mark Eldredge, and John C. Parker.

In accordance with the bylaws of the Lamme Medal committee, the board confirmed the president's appointment of F. F. Brand, Howard Maxwell, and C. A. Powel as members of that committee for the term of three years beginning August 1, 1939, and of R. E. Hellmund to serve for the unexpired term, ending July 31, 1940, of C. F. Hirshfeld, who resigned from the committee shortly before his death.

There was considerable discussion as to whether the committee on legislation affecting the engineering profession had the proper title and whether its functions should include those of the special committee on Model Registration Law, the past activities of the legislation committee having dealt largely with licensing matters. C. R. Beardsley, chairman of the special committee on Model Registration Law and newly appointed chairman of the committee on legislation affecting the engineering profession, recommended the combination of the two committees' functions, the personnel of the special committee to be included in the membership of the legislation committee for the present year. Therefore, as the work originally assigned to the special committee has been completed, it was voted to discharge the special committee on Model Registration Law with sincere appreciation of its services.

Representatives of the Institute on various organizations were appointed for the one-year term beginning August 1, 1939. O. W. Eshbach was appointed a representative on the Engineers' Council for Professional Development for the three-year term beginning October 1939; W. S. Barstow was reappointed a representative on the library board, United Engineering Trustees, Inc., for a four-year term beginning in October 1939; and L. W. Chubb was nominated for reappointment by the Engineering Foundation Board as the Institute representative on the research procedure committee of the Foundation.

Local honorary secretaries were appointed for the two-year term beginning August 1, 1939, as follows: A. F. Enstrom for Sweden; A. P. M. Fleming for England; and P. H. Powell for New Zealand.

Other matters were discussed, reference to which may be found in this or future issues of ELECTRICAL ENGINEERING.

Future AIEE Meetings

Great Lakes District Meeting
Minneapolis, Minn., September 27–29, 1939

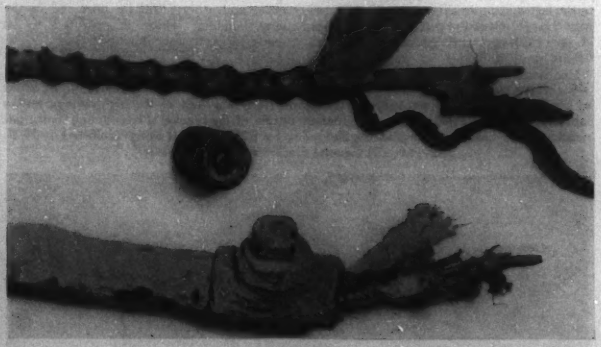
Middle Eastern District Meeting
Scranton, Pa., October 11–13, 1939

Winter Convention
New York, N.Y., January 22–26, 1940

Summer Convention
Swampscott, Mass., June 24–28, 1940

Pacific Coast Convention
Vancouver, B. C., August 27–30, 1940

Conduit 64 Years Old Found at Cornell



SECTIONS of wrought-iron pipe, found by workmen digging on the campus of Cornell University, Ithaca, N. Y., have been identified as part of the conduit laid in 1875 for what is said to be the first outdoor electric-lighting system in the Western Hemisphere. Electricity for lights on the campus was provided by a dynamo built in the Cornell shops in 1875. The dynamo is still capable of being used, and, according to the electrical-engineering school faculty, the pipe could also still perform its original function. Strips of muslin were used to protect the copper wire in the center of the pipe and the intervening space was filled with beef tallow secured for the experiment from a local butcher. The illustration shows pipe, wire, and method of insulation.

Coffin Medal Awarded. The Charles A. Coffin Medal, awarded annually for distinguished contribution to the development of electric light and power for the convenience of the public and the benefit of the industry, was won for 1938 by the Wisconsin Electric Power Company. The medal, with $1,000 for the employees' welfare

fund, was presented at the recent annual meeting of the Edison Electric Institute, New York, N. Y., by H. P. Liversidge (A'12, M'17) president of the Philadelphia (Pa.) Electric Company and chairman of the EEI prize awards committee. The committee cited the company's notable record in all major fields of activity, including technical accomplishment, public and employee relations, operating efficiency, financial management, over-all operation.

1939 Utility Chart. Spoken of as "a public utility manual in convenient chart form," a 34 by 28 inch chart showing at a glance interrelation and capitalization of the principal public-utility holding, operating, and investment companies as of June 1, 1939, has been issued by Robert A. Burrows, Statistician, First National Bank Building, Pittsburgh, Pa. Available either in plain black and white ($2) or in nine distinctive colors ($3) to help in tracing relationships, the chart covers comparative data for 45 major systems including interrelations of all voting stock, outstanding capitalization, per cent classification of gross revenues for various services, gross revenues in dollars, operating ratio in per cent, net income in dollars, sheer earnings, outstanding stocks, and so on. Also shown are service-area maps of the principal public-utility systems in the United States.

Oilless Circuit Breakers Demonstrated to Utility Engineers

TWO circuit breakers recently developed by the General Electric Company were given demonstration tests under short-circuit conditions before a group of 270-odd utility and industrial engineers and executives, gathered at the high-power testing laboratory of the company's Schenectady works August 17, 1939.

The unit demonstrated in the morning's period of tests was a 15-kv 600-ampere air-blast circuit breaker having a rated interrupting capacity of 500,000 kva at 60 cycles. This was a three-phase, completely enclosed, air-operated cubicle-type unit, intended for power-station or industrial applications. Similar in general dimensions to the company's long-established *H*-type oil circuit breakers, the unit reflects the first serious attempt to apply to American power systems a principle of circuit interruption that has prevailed for some time and in various forms in Europe, where the concentrations of power are notably less. Duty cycles imposed on this breaker during demonstration tests included opening a short circuit of 630,000 kva, and a close-open cycle against a short circuit of 730,000 kva. In the first instance, the circuit was cleared within 5.9 cycles (60-cycle basis) of the initial tripping impulse and 0.3 cycle after the arc was struck by the parting contacts; in the latter instance these respective figures were 6.0 cycles and 0.5 cycle. Examination of the vital parts after a series of seven tests revealed amazingly little wear on either the moving or stationary contacts.

The afternoon's series of tests was applied to an oilless breaker utilizing a special adaptation of the magnetic-blowout principle. The three-phase five-kv unit tested had a normal rating of 1,200 amperes and an interrupting capacity of 100,000 kva at 60 cycles. Opening a short circuit of 140,000 kva, this breaker cleared the circuit within 4.3 cycles (60-cycle basis) of the initial tripping impulse; 0.3 cycle after the arc was struck. In a close-open cycle against a 125,000-kva short circuit, the circuit was cleared within 4.8 cycles of the initial tripping impulse; 0.7 cycle after the arc was struck.

Acting as informal master of ceremonies and commentator for the tests, D. C. Prince (A'16, F'26) chief engineer of the company's Philadelphia works, pointed out that the breakers, no longer in the laboratory stage, are ready for regular service. Their design has overcome two important limitations of European-type air circuit breakers, inability to handle high voltages, and difficulty of standardization, he declared. Both breakers permit standard arrangement of busses, current transformers, mechanical interlocks, and associated devices.

The air-blast circuit breaker demonstrated August 17, 1939, at the Schenectady, N. Y., works of the General Electric Company, is here shown (left) in a vault of the high-voltage testing laboratory. Below, stationary arcing contact of one of the breaker's interrupting units, undamaged after tests exceeding interrupting rating by 50 per cent, is being exhibited by H. E. Strang (A'28) General Electric switchgear engineer

Bell Laboratories to Add New Building

Construction of a new laboratory unit at Murray Hill, N. J., has been authorized by the board of directors of Bell Telephone Laboratories. The building, which is expected to cost about $3,000,000, will house about 800 persons, or 17 per cent of the personnel of the Laboratories. Laboratories for several divisions of the research and apparatus development departments, including physical research, standards, outside plant development, material standards, and others, will be provided in the new building, which is expected to be ready for occupancy during 1941.

Current Items From American Engineering Council

Registration of Engineers in the District of Columbia

Although legislation providing for the registration of engineers in the District of Columbia did not become law before the first session of the 76th Congress adjourned, it passed the Senate on July 18 and is now pending before the Committee on the District of Columbia of the United States House of Representatives. This is more progress toward enactment than has hitherto been made by any of the similar measures introduced in preceding Congresses.

The proposed legislation, introduced by Senator King in the Senate (S.1128) and Representative Randolph in the House of Representatives (H. R. 4792), has had the united support of the engineering organizations of the District of Columbia acting through the Council of Engineering and Architectural Societies.

Through extended conferences and hearings, the subcommittee of the Senate District Committee in charge of the legislation made every effort to present to the Senate a bill that would be representative of the point of view of engineers and engineering organizations within the District, and was successful to the extent that the Senate passed the legislation as reported with almost no debate and with no amendments other than those recommended by the committee.

Encouraged by the approval of the Senate, those supporting the measure were hopeful that the House District Committee would report the Randolph bill favorably at its meeting of July 21. However, between the date of passage of the King bill in the Senate and the July 21 meeting of the House District Committee, representatives of several national organizations emphatically protested enactment of the legislation until its provisions had been broadened. Since the House District Committee had given no consideration to the matter other than to refer it to the District Commissioners and to its own subcommittee on the Judiciary for study and report, a few of its members felt that the committee did not have sufficient information on which to base action and expressed the belief that further hearings probably should be held. As a result the House District Committee voted to hold the Randolph bill in committee until Congress reconvenes in January, at which time the legislation will be taken up again.

Future Meetings of Other Societies

American Chemical Society. Fall meeting, September 10–15, Boston, Mass.

American Institute of Physics. Temperature symposium, November 2–4, New York, N. Y.

American Physical Society. 230th meeting, December 1–2, Chicago, Ill.
231st meeting, December.
Annual meeting (232d), December 28–30, Columbus, Ohio.

American Society of Mechanical Engineers. Joint meeting ASME Fuels Division, AIME Coal Division, October 5–7, Columbus, Ohio.
Annual meeting, December 4–8, New York, N. Y., and Philadelphia, Pa.

Association of Iron and Steel Engineers. Annual convention, September 26–29, Pittsburgh, Pa.

Conference on Electrical Insulation (National Research Council). November, Cambridge, Mass.

Electrochemical Society. Fall convention, September 11–13, New York, N. Y.

Institute of Radio Engineers. 14th annual convention, September 20–23, New York, N. Y.
Fall meeting, November 13–15, Rochester, N. Y.

National Electrical Contractors Association. October 9–12, Philadelphia, Pa.

National Electrical Manufacturers Association. October 23–27, Chicago, Ill.

National Safety Council. October 16–20, Atlantic City, N. J.

Société Française des Électriciens. Television meeting, November, Paris, France.

Society of Automotive Engineers. National aircraft production meeting, October 5–7, Los Angeles, Calif.

Congress Acts to Improve Patent Procedure

Of the several bills introduced into Congress to improve patent procedure, as a result of testimony before the Temporary National Economic Committee, five were passed by both the House of Representatives and the Senate. It is anticipated that they will be signed by the President promptly since the legislation proposed now has the approval of the Department directly affected, the Department of Commerce. They are:

H. R. 6872. Reduction in the time allowed for public use of an invention before applying for a patent from two years to one year.

H. R. 6873. Simplification of the present interference practice, which decides which of two conflicting applications shall be granted, by referring the matter to a three-man board of interference examiners and issuing a patent immediately in consonance with their decision. Thereafter the losing party can, if he wishes, appeal the matter but the present long delay in issuance whenever such appeal is taken is eliminated.

H. R. 6874. Reduction of the time for paying the final patent fee from six to three months after notice that the application has been approved. The Commissioner is given discretion to extend this time an additional year if justification for the delay is demonstrated.

H. R. 6875. Limitation of the time for copying claims into an application from prior patents to those issued within one year, rather than two.

H. R. 6878. Reduction in the allowed time for responding to Patent Office communications from the present six months to not less than 30 days, at the discretion of the Commissioner.

At the time these bills were before the Senate for consideration, Senator O'Mahoney presented to the Senate the recommendations of the Temporary National Economic Committee with respect to patent procedure and pointed out that H. R. 6872 was the fifth of the Temporary National Economic Committee recommendations, H. R. 6873 the third, H. R. 6874 the fourth, H. R. 6875 the sixth, and H. R. 6878, the seventh.

Two other bills are on the Senate calendar which have not yet received the approval of that body. They are:

S. 2687. Setting up a single Court of Patent Appeals to which shall be referred all appeals from decisions of U. S. District Courts regarding patent cases.

S. 2688. Termination of the life of a patent at 17 years after date of issue or 20 years after date of application, whichever is shorter. The former has been passed over on each occasion it has been due for discussion. The latter was passed but returned to the calendar for further consideration.

H. R. 6721. Providing for reclassification of Patent Office records by a force of 25 additional examiners whose entire time shall be devoted to the task—has been passed by the House of Representatives but has not been reported by the Senate Patents Committee.

Senator O'Mahoney pointed out that "other patent recommendations made by the Temporary National Economic Committee deal rather with the uses to which patent privileges are put in the control of industry" and that "no bills had been introduced by any congressional member of the TNEC dealing with these recommendations because of the desire of TNEC that full consideration be given to the recommendations which have been made."

Letters to the Editor

CONTRIBUTIONS to these columns are invited from Institute members and subscribers. They should be concise and may deal with technical papers, articles published in previous issues, or other subjects of some general interest and professional importance. ELECTRICAL ENGINEERING will endeavor to publish as many letters as possible, but of necessity reserves the right to publish them in whole or in part, or reject them entirely.

ALL letters submitted for consideration should be the original typewritten copy, double spaced. Any illustrations submitted should be in duplicate, one copy to be an inked drawing but without lettering, and the other to be lettered. Captions should be furnished for all illustrations.

STATEMENTS in these letters are expressly understood to be made by the writers; publication here in no wise constitutes endorsement or recognition by the American Institute of Electrical Engineers.

Kirchoff's Equations in a Many-Dimensional Representative Space

To the Editor:

Referring to my letter on the subject in ELECTRICAL ENGINEERING, May issue, page 225, my attention has been called to the fact that Professor E. A. Guillemin of the Massachusetts Institute of Technology has previously used a many-dimensional current vector orthogonal to the subspace formed by the vectors of the network parameters ("Communication Networks," 1931, volume 1, chapter 7, page 256). This anticipates

my proposition I. I am glad to be corrected especially in view of the fact that in the same chapter of Professor Guillemin's book an interested person will find further details that will facilitate an application of the general propositions to electrical network problems.

Very truly yours,
VLADIMIR KARAPETOFF (A'03, F'12)

(Professor emeritus of electrical engineering, Cornell University, Ithaca, N. Y.; consulting engineer, Leonia, N. J.)

Bus Protection

To the Editor:

In TRANSACTIONS, May section, an AIEE-EEI committee report classified bus-protection schemes and stated that the fault bus gave protection against ground faults only. Although this is true in a sense, it is rather unfair to those fault bus installations in which the fault current may not reach the ground or ground bus, but may be essentially confined to the fault bus, and the resultant ground current may be negligible or zero. In the company by which the writer is employed, some of the fault bus schemes are "residual" and the others "three phase." In the three-phase type each phase has a separate fault bus conductor and a separate current transformer, or the equivalent. The three current transformer secondaries are of such ratios and so connected that the relay current is never zero regardless of the number of phases involved with respect to the fault bus. On a completely isolated-phase bus structure, an adequate three-phase fault bus gives protection that is as complete as the most complete differential installation. On a group-phase structure this is not true, but it does give protection against what is probably the most drastic type of interphase fault, namely, that in which ground connections are left on the phases of a bus which is out of service, and live apparatus is closed to this bus in an operating error. Since the grounds which were not removed are tied to the fault bus, the fault-bus relay immediately opens the switch which was closed in error. With three symmetrical ground connections, no ground current is involved.

Very truly yours,
GEORGE W. HAMPE (A'28)

(Engineer, testing department, Commonwealth Edison Company, Chicago, Ill.)

Magnesium-Copper Sulphide Rectifier Battery Charger

To the Editor:

In the June section of the TRANSACTIONS there is a paper by C. A. Kotterman dealing with the application of dry-type rectifiers for charging the batteries for railroad passenger cars. In this article Mr. Kotterman refers to the three widely known types of dry-type rectifiers, namely, the copper oxide, the iron-selenium, and the magnesium-copper sulphide rectifiers. He states "the iron-selenium rectifier has never been considered seriously as a heavy-duty type."

I wish to correct Mr. Kotterman in this statement. The selenium-type rectifier is today the most important dry-type rectifier for power purposes and, whilst it has not been used largely on this continent, I have just completed the testing of a selenium-iron rectifier which has a normal rating of 45 amperes at 65 volts. This is being used for automatic mine locomotive battery charging, and by means of the associated choke, gives the desired characteristics for an eight-hour taper charge required for this class of work. The over-all efficiency of the entire equipment tests out to 65 per cent, this being measured from the a-c input to the 440-volt transformer, to the d-c output. I have had occasion to use selenium-iron rectifiers for other applications in the last year or so, and if Mr. Kotterman will refer to a recent book "Trockengleichrichter, Theorie, Aufbau und Anwendung" (Dry Rectifiers, Theory, Construction and Application) by Karl Maier, published by R. Oldenbourg of Munich and Berlin in 1938, he will find a great deal of information regarding the use and application of selenium-iron rectifiers. They are used for electrolytic purposes arranged in groups for delivering as much as 5,000 amperes at 6 and 12 volts, and for delivering one-half ampere at 4,000 volts and at almost every conceivable application falling between these ranges. In certain applications they can be designed for over-all efficiencies of 75 per cent and 80 per cent including the transformer.

Yours very truly,
F. J. BARTHOLOMEW (A'26, M'35)

(President, Electric Power Equipment, Ltd., Vancouver, B. C., Canada)

Personal Items

H. T. Friis (A'20, M'26) research engineer, Bell Telephone Laboratories, New York, N. Y., has been awarded the Morris Liebmann Memorial Prize for 1939 by the Institute of Radio Engineers. The award was

H. T. FRIIS

conferred in recognition of "his investigations in radio transmission, including the development of methods of measuring signals and noise and the creation of a receiving system for mitigating selective fading and noise interference." A native (1893) of Denmark, Mr. Friis received the degree of electrical engineer from the Royal Technical College, Copenhagen, in 1916. He did research at that institution and was technical adviser to the Royal Gun Factory in Copenhagen, before coming to the United States in 1919 for graduate study at Columbia University on a fellowship from the American Scandinavian Foundation. He was a research engineer with Western Electric Company, New York, N. Y., from 1920 until 1925, when he became associated with the Bell Laboratories.

C. E. Oakes (A'17, M'20) has been elected president of the Birmingham Electric Company, Birmingham, Ala., and will also serve the company as general manager. A native (1892) of Pendleton, Ore., Mr. Oakes received the degrees of bachelor of science in electrical engineering from Oregon Agricultural College in 1915 and of master of mechanical engineering from Cornell University in 1917. He was an assistant instructor and later instructor in electrical engineering at Oregon Agricultural College, Corvalis, in 1914–16, and in 1917 was appointed assistant electrical engineer for the Bureau of Standards, Washington, D. C. He was later employed by the Federal Power Commission, before becoming associated with the Pennsylvania Power and Light Company in

C. E. OAKES

1923. He continued with that company until his recent appointment, having been manager of the Allentown (Pa.) division since 1927.

Vladimir Karapetoff (A'03, F'12) retired in June 1939 as professor of electrical engineering at Cornell University, Ithaca, N. Y., and has been made professor emeritus by the trustees of the university. Born in St. Petersburg (Leningrad), Russia, January 8, 1876, he received the degrees of civil engineer (1897) and master of mechanical engineering (1902) from the Imperial Institute of Ways of Communication, Leningrad, and studied electrical engineering at the Polytechnic Institute, Darmstadt,

Germany, in 1899–1900. He also received the honorary degrees of doctor of music from New York College of Music, 1934, and of doctor of science from Brooklyn Polytechnic Institute, 1937. He came to America on a traveling fellowship in 1903, becoming a special engineering apprentice with Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa. He joined the Cornell faculty in 1904 as assistant professor of electrical engineering, becoming professor in 1908. He has been consulting engineer to a number of organizations and will continue his consulting practice. He has been a trustee of Ithaca College, Ithaca, N. Y., since 1933, and holds a commission as lieutenant commander in the United States Naval Reserve Forces. Inventor of electrical devices and musical instruments, and author of numerous technical books and articles, Doctor Karapetoff is a member of a number of honorary and technical societies and has received the Montefiore Medal of the Belgian Association of Electrical Engineers (1923) and the Eliot Cresson Medal of the Franklin Institute (1927).

J. D. Noyes (A'07, M'20) engineer on the president's staff of the Detroit Edison Company, Detroit, Mich., retired recently. Born in Baraboo, Wis., in 1880, Mr. Noyes received the degree of bachelor of science in electrical engineering from the University of Wisconsin in 1904, and the same year became a student apprentice of Westinghouse Electric and Manufacturing Company, at East Pittsburgh, Pa. He was transferred to Philadelphia in 1906, where he was an engineer in the construction department, and two years later was transferred to the company's Detroit sales office, where he continued until 1914, specializing in factory power applications. He went with the Detroit Edison Company as a sales engineer in 1914, becoming senior sales engineer in 1918, and being assigned to the president's staff in 1926.

D. M. Jones (A'21) has been appointed manager of the engineering division of the central station department, General Electric Company, Schenectady, N. Y. A native (1886) of Cambria, Wis., Mr. Jones received the degrees of bachelor of arts (1905) from the University of Minnesota, and bachelor of science (1917) from Massachusetts Institute of Technology. From 1905 to 1914 he was engaged in electrical operation and construction. He started with General Electric in 1917 in the student test course, entering the lighting engineering department in 1918, and the central station department in 1923. Before his recent appointment he was in charge of the sponsor engineers section of the department.

W. C. Johnson, Jr. (A'29) has been appointed director of placement and associate professor of vocational guidance at Virginia Polytechnic Institute, Blacksburg. After receiving the degrees of bachelor of science at Princeton University, 1925, and electrical engineer, Rensselaer Polytechnic Institute, 1927, he was associated with General Electric Company in the testing and design departments, as instructor in engineering courses, and as consultant to the air-conditioning department. From 1933 until his present appointment he has been assistant professor of physics and field secretary on admissions at Rensselaer Polytechnic Institute, Troy, N. Y.

E. M. Melton (A'36) sales engineer with Canadian National Carbon Company, Ltd., and Acheson Graphite Corporation, has been transferred to Calcutta, India, to represent those organizations in the Far East. He has been associated with National Carbon Company, Inc., on application and sale of carbon products since 1933, and since 1936 had been in the New York metropolitan district.

B. M. Jones (A'20, M'24) has been appointed chairman of the electrical section of the Engineers' Society of Western Pennsylvania. Mr. Jones, who is also chairman of the membership committee of the AIEE Pittsburgh Section, is division engineer of system planning, Duquesne Light Company, Pittsburgh, Pa.

G. H. Temple, Jr. (A'38) formerly a research assistant at Massachusetts Institute of Technology, Cambridge, has become associated with A. G. Spalding and Brothers, New York, N. Y., in charge of operation of a multi-flash stroboscopic light source used for photographic analysis of golf swings.

H. J. MacLeod (A'23) professor and head of the department of electrical and mechanical engineering, University of British Columbia, Vancouver, B. C., Canada, has been appointed technical advisor to the British Columbia Public Utilities Commission.

H. T. Plumb (A'03, M'21) has been appointed consulting engineer for the Rocky Mountain district by General Electric Company. He will have headquarters at Denver, Colo. He has been with the company since 1910, and since 1912 has been local engineer at the Salt Lake City office.

H. R. Summerhayes (A'07, M'16) has been appointed consulting engineer of the central station department, General Electric Company, Schenectady, N. Y. He had been manager of the engineering division of that department since 1925.

G. A. Mills (M'18) formerly president of the Kansas Electric Power Company, Lawrence, Kans., has been transferred to the Corpus Christi, Tex., office of the Central Power and Light Company, where he will be employed in a special capacity.

C. C. Long (A'14, M'30) senior electrical engineer, Metropolitan Water District, City of Los Angeles, Calif., has a temporary assignment with the Bonneville Project, Portland, Ore., during a three-month leave of absence from his Los Angeles position.

G. T. Harness (A'30, M'36) instructor in electrical engineering at Columbia University, New York, N. Y., has been promoted to the rank of assistant professor.

P. R. Roehm (A'38) formerly assistant engineer with New Orleans (La.) Public Service, Inc., has become associated with Ebasco Services, Inc., New York, N. Y.

A. E. Allen (A'06, M'13) formerly vice-president, Westinghouse Electric and Manufacturing Company, Mansfield, Ohio, has been elected a director of Landers, Frary and Clark, New Britain, Conn.

J. A. Mayer (A'37) formerly manager of the Cleveland, Ohio, office of the Graybar Electric Company, has been appointed supply sales manager, with headquarters in New York, N. Y.

F. H. Murphy (A'07, F'30) consulting engineer, Portland General Electric Company, Portland, Ore., has been appointed a member of the Oregon State Board of Engineering Examiners.

A. D. Colvin (A'09, M'13) executive vice-president, Connecticut Power Company, New London, has been appointed a member of the Groton-New London bridge commission.

Obituary

Lancelot Richard Woodcock (A'09, M'20) divisional chief, Ebro Irrigation and Power Company, Barcelona, Spain, died July 1, 1939, at Barcelona. Born July 10, 1880, at Warwick, Queensland, Australia, he received the degree of bachelor of engineering in mechanical and electrical engineering from the University of Sydney in 1905. From 1896 to 1898 he served an apprentice course with Barton and White, electrical engineers, Brisbane. After graduation he was an assistant lecturer in mechanical engineering at the University of Sydney, Sydney, New South Wales, in 1905–06. Coming to the United States he was employed by the General Electric Company, Schenectady, N. Y., in the testing and turbine powerhouse departments, in 1907 and 1908, and in the latter year became associated with the Washington Water Power Company, Spokane, on construction of hydroelectric power plants. In 1915 he returned to Australia and became manager of the electrical department of the Engineering Supply Company of Australia, Brisbane. During 1917–18 he was assistant electrical engineer, factories branch, Ministry of Munitions, London, England. In 1919 he first became associated with the Ebro Irrigation and Power Company as resident engineer at Barcelona. From 1921 to 1923 he was in New York, N. Y., as engineer on the construction of the Hell Gate power station, for the Brooklyn (N. Y.) Edison Company, and on the Sherman Creek power station. He was general superintendent at the Sivasamudram power plant of the Mysore Government, India, 1924–26, and in 1927 returned to the Ebro Irrigation and Power Company as divisional chief at Tremp, Spain. He continued in that position until recalled after the outbreak of the Spanish Civil War in 1936, returning in April 1938.

Frederick Milton Servos (A'19, M'27) whose death on July 8, 1939, was mentioned in the August issue, page 363, was born October 25, 1894, in Niagara township, Ontario, Canada. He received the degree of bachelor of applied science in the electrical-engineering department of the Uni-

versity of Toronto in 1914, and in the same year was employed as an engineering assistant by the Public Utilities Commission of the City of St. Catharines, Ont., becoming superintendent in 1916. In 1918 he became works manager of Tudhope Electro Metals, Ltd., Vancouver, B. C., and in 1919 was employed as an electrical engineer by the United States Ferro Alloys Corporation, Niagara Falls, N. Y. He was electrical and mechanical superintendent for the Canadian Electric Steel Company, Ltd., Montreal, Que., in 1920–21. In 1922 he was employed by the Canadian and General Finance Company, Ltd., Toronto, Ont., subsidiary and consulting and purchasing agent for the Brazilian Traction, Light, and Power Company, Ltd. He became electrical engineer in charge of electrical work in the Toronto office in 1923, and in 1924 was transferred to the parent organization in Rio de Janeiro, Brazil, as chief electrical engineer for a group of companies controlled by the Brazilian Traction Light and Power Company, including the Rio de Janeiro Tramway Light and Power Company, Ltd., Sao Paulo Tramway Light and Power Company, Ltd., Brazilian Hydro Electric Company, Ltd., Sao Paulo Electric Company, Ltd. He was returning to Ontario for reasons of health at the time of his death. He was AIEE local honorary secretary for Brazil from 1927 until his departure from Brazil in 1939.

Hugh McCollum Beugler (A'03, M'27) retired consulting engineer, died at Hamden, Conn., July 16, 1939. He was born in Williamsport, Pa., November 26, 1872, and studied at Cornell University. In 1888 he became associated with the Thomson-Houston Company where he worked on various assignments involving design and construction of power plants, electric lighting systems, and gas and water installations. During the period 1894–1900 he was with the Brush-Swan Electric Light Company, Ithaca, N. Y., and the Ithaca Street Railway, as superintendent of operation. He engaged in special engineering jobs in 1900–01, before becoming general superintendent and chief engineer of the Elmira (N. Y.) Water, Light, and Railroad Company, a position which he held until 1906 and returned to in 1908 after brief associations with Ford, Bacon, and Davis, New York, N. Y., and Day and Zimmerman, Philadelphia, Pa. From 1909 to 1911 he was manager of the electrical department, Newburgh (N. Y.) Light, Heat, and Power Company, and in 1911 he became operating manager of the Central Hudson Gas and Electric Company, Poughkeepsie, N. Y. He became a vice-president of the company in 1926, and in 1927 retired to engage in general consulting practice.

Joseph Walter Ramsay (A'36, M'38) professor of electrical engineering, University of Texas, Austin, died July 22, 1939. Born November 25, 1880, at Bloomington, Ind., he received the degrees of bachelor of science in electrical engineering from Texas Agricultural and Mechanical College in 1906, bachelor of science in electrical engineering and electrical engineer from the University of Texas in 1916. From 1906 to 1908 he was a student apprentice with Westinghouse Electric and Manufacturing Company, Pittsburgh, Pa. During the next three years he was employed in various capacities by the Benton Harbor-St. Joseph (Mich.) Light and Power Company, the Southern Pacific Railway, and the Barden Electric and Machinery Company, Houston, Tex. In 1911 he became an instructor in the department of electrical engineering at the University of Texas, Austin, where he continued until 1917. During the World War he served as lieutenant and captain in the United States Army, with air service troops at Kelly Field, Tex., and on the Mexican border, and was in charge of aerial gunnery at the School of Military Aeronautics, located at the University of Texas. He became professor of applied electricity at Washington State College, Pullman, for the term 1919–20, and in 1920–21 was assistant professor of electrical engineering at Texas Agricultural and Mechanical College, College Station. In 1921 he returned to the University of Texas with the rank of associate professor, becoming full professor in 1938. He was a member of the Society for the Promotion of Engineering Education, and Eta Kappa Nu.

John P. Garvin (A'23, M'29) resident engineer, New York State Electric and Gas Company, Elmira, died May 12, 1939. Born in Minneapolis, Minn., July 26, 1891, he received the degree of bachelor of science in electrical engineering from Montana State College in 1917. He served in the United States Army during the World War as a second lieutenant in the Coast Artillery. From 1919 to 1926 he was employed successively as engineer by the Montana State Highway Department, operator at the Holter plant of the Montana Power Company and at the Tumwater plant of the Great Northern Railway; junior electrical engineer, United States Bureau of Mines, Pittsburgh, Pa.; and switchboard engineer, Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa. In 1926 he became central station layout engineer for W. S. Barstow and Company, Reading, Pa. Later he was electrical engineer for the Metropolitan Edison Company, and resident engineer for the E. M. Gilbert Engineering Corporation, both at Reading, before assuming the position with the New York State Company which he held at the time of his death.

George David Wilkinson (A'25) assistant automatic chief, Western Union Telegraph Company, New York, N. Y., died July 5, 1939. He was born at Rochester, N. Y., May 1, 1881, and took electrical courses at the Mechanics Institute in Rochester and at Lowell Institute. In 1896 he became a telegraph operator for Postal Telegraph Cable Company, Rochester, and later occupied the same position with Western Union Company, Boston, Mass., and the New York, New Haven, and Hartford Railroad Company, Boston. He became employed by the American Telephone and Telegraph Company, Boston, in 1900, and in 1902 was made exchange manager of New England Telephone and Telegraph. From 1907 to 1910 he was with Western Union in Boston, from 1910 to 1914 with Postal Telegraph Cable Company, New York, N. Y. He became assistant automatic chief and instructor in automatic telegraphy for Western Union in New York in 1914, and except for a period with the United States Army Signal Corps as instructor in telegraphy and consulting engineer, continued with that company in various positions until his death.

Ottomar Carl Spangenberg (A'16), electrician, Mount Sinai Hospital, New York, N. Y., died June 6, 1937, according to information recently received. He was born May 8, 1860, at Koenigsberg, Germany, and came to the United States in 1871. He studied at private schools and at Stevens Institute of Technology and Cooper Union. In 1881 his electrical experience began in the Weston shops of the United States Electric Light Company, Newark, N. J., afterward the shops of the Westinghouse Electric and Manufacturing Company. He went to Philadelphia, Pa., in 1886 as foreman for Rees and Fitzgerald, and in 1888 was employed by the Queen City Electric Company, Cincinnati, Ohio, to do experimental work. He later engaged in independent construction of dynamos and installed plants for the Continental Dynamo Company, New York, N. Y., and others. In 1905 he became electrician at Mount Sinai Hospital, having charge of lights, power, heating devices, and medical electrical devices, including X-ray apparatus, and continued there until his death.

Benjamin Franklin Cleaves (A'23) vice-president in charge of operation, Pennsylvania Edison Company, Altoona, Pa., died July 30, 1939. Born June 28, 1885, at Addison, Maine, he studied engineering at Lowell Institute. During 1904 and 1905 he was with the Westinghouse Electric and Manufacturing Company at East Pittsburgh, Pa., and from 1906 to 1911 with the General Electric Company at Lynn, Mass. In 1911 he was employed by what was then the Penn Central Light and Power Company, Altoona, as engineer of tests. He became electrical engineer in 1916, assistant superintendent of operations in 1924, general superintendent of operations in 1925, vice-president in 1928, and retained the last-named position when the company became the Pennsylvania Edison Company. He was chief engineer of the Municipal Service Company, Altoona, from 1929 to 1931, and vice-president from 1931 to 1935. He was a member of the Edison Electric Institute.

Emmons Thomas Gray (A'23) manager of electrical distribution, Central Hudson Gas and Electric Company, Poughkeepsie, N. Y., died July 6, 1939. He was born August 1, 1896, at Fitchburg, Mass., and received the degree of electrical engineer from Rensselaer Polytechnic Institute in 1922. During the World War he was a pilot in the air service of the United States Army. He was later employed by the Troy (N. Y.) Gas Company, electrical department, and by the Depew and Lancaster Light, Power, and Conduit Company, Lancaster, N. Y., as head of the engineering

department, and later as general superintendent. He was employed by the Central Hudson Gas and Electric Company as district operating superintendent, later becoming division superintendent, and for several years had been in charge of electrical distribution. He had been with the company about 13 years.

Clifton Penn Hughes (M'39) director of Hackbridge Electric Construction Company, Ltd., and Hewittic Electric Company, Ltd., Hersham Works, Walton-on-Thames, England, died July 7, 1939. He was born at Penarth, Wales, February 11, 1905, and was educated at Oundle School and Manchester Technical College. He was an apprentice engineer at Metropolitan Vickers Electrical Company, Ltd., Manchester, England, 1924–26, and at Westinghouse Electric and Manufacturing Company, Sharon, Pa., and Pittsburgh, Pa., 1927–28. He became assistant manager of the Hackbridge company in 1929, and assumed the position of director of the Hackbridge and Hewittic companies in 1935.

Membership

Applications for Election

Applications have been received at headquarters from the following candidates for election to membership in the Institute. Names of applicants in the United States and Canada are arranged by geographical Districts. If the applicant has applied for direct admission to a grade higher than Associate, the grade follows immediately after the name. Any member objecting to the election of any of these candidates should so inform the national secretary before September 30, 1939, or November 20, 1939, if the applicant resides outside of the United States or Canada:

United States and Canada

1. NORTH EASTERN

D'Esopo, F. P., Wiremold Company, Hartford, Conn.
Hall, W. M., Massachusetts Institute of Technology, Cambridge.
Kent, M. F., General Electric Company, Schenectady, N. Y.
Shea, D. J. (Member), Charles T. Main, Inc., Boston, Mass.

2. MIDDLE EASTERN

Barlow, P. M. (Member), West Virginia Engineering Company, Charleston.
Brecht, W. A. (Member), Westinghouse Electric and Manufacturing Company, East Pittsburgh Pa.
Warrington, C. M. (Member), Pennsylvania Power and Light Company, Sunbury.

3. NEW YORK CITY

Bozzella, S. J., Davis Street, Locust Valley, N. Y.
Holbrook, B. D., Bell Telephone Laboratories, Inc., New York, N. Y.
Nauman, O. H., Long Island Lighting Company, Glenwood Landing, N. Y.
Rudolph, E. W. (Member), Petroleum Heat and Power Company, Inc., New York, N. Y.
Snow, H. B. (Member), Public Service Electric and Gas Company, Newark, N. J.
Walker, D. B. (Member), Moore McCormick Line, New York, N. Y.

4. SOUTHERN

Bush, L. R., 419 Palmer Building, Atlanta, Ga.
Callaway, J. L., Taylor County Electric Membership Corporation, Reynolds, Ga.
Coulbourn, E. R. (Member), Alabama Power Company, Birmingham.
Watson, M. P., United Gas Pipe Line Company, Monroe, La.

5. GREAT LAKES

Hinshaw, W. W., University of Illinois, Urbana.
Larson, S. C., General Electric X-Ray Corporation, Chicago, Ill.
Sumpter, P. B., Commonwealth and Southern Corporation, Jackson, Mich.
Van Wingen, P. M., Commonwealth and Southern Corporation, Jackson, Mich.

6. NORTH CENTRAL

Caulkins, L. B., Dakota Power Company, Rapid City, S. D.
Martinsen, R. E., Union Pacific Coal Company, Road Springs, Wyo.
Slaybaugh, G. D., Public Service Company of Colorado, Denver.
Thompson, W. F., Public Service Company of Colorado, Denver.

7. SOUTH WEST

Hebert, A. C., C. A. & N. University, Langston, Okla.
Stewart, W. H., Sun Oil Company, Sun Pipe Line Company, Beaumont, Tex.

8. PACIFIC

Bowler, J. A., 1178 West Duarte Road, Arcadia, Calif.
Dilberger, H. A., Pacific Gas and Electric Company, Oakland, Calif.
Freeman, M. G., Gardner Electrical Manufacturing Company, Emeryville, Calif.

Total, United States, 30

Elsewhere

Datar, D. K., The Municipal Committee, Hinganghat (CP), India.
Nelson, J., General Electric S/A, Sao Paulo, Brazil, South America.
Shah, T. M. (Member), Rohtas Industries, Ltd., Dalmianagar District, Shahabad, Bihar, India.
Sheppard, J. H. G., Engineering Supply Company of Australia, Ltd., Brisbane, Queensland.

Total, elsewhere, 4

Addresses Wanted

A list of members whose mail has been returned by the postal authorities is given below, with the addresses as they now appear on the Institute records. Any member knowing of corrections to these addresses will kindly communicate them at once to the office of the secretary at 33 West 39th St., New York, N. Y.

Coleman, Irwin M., 581 Academy St., New York, N. Y.
Ebert, Kenneth W., 776 N. Cass St., Milwaukee, Wis.
Hall, John R., c/o Patrick Tyrrell Drilling Co., Cotton Exchange Bldg., Houston, Texas
James, George Hazard, Jr., 7 Meikle Ave., Newport, R. I.
McCarthy, C. C., c/o Westinghouse Electric and Manufacturing Co., 814 Ellicott Square, Buffalo, N. Y.
Modisette, M. H., 4514—16th St., N. E., Seattle, Wash.
Strauss, Walter A., 39 West 69th St., New York, N. Y.

7 Addresses Wanted

Engineering Literature

New Books in the Societies Library

Electrical engineers may be interested in the following new books, which are among those recently received at the Engineering Societies Library, New York, N. Y. Unless otherwise specified, books listed have been presented by the publishers. The Institute assumes no responsibility for statements made in the following summaries, information for which is taken from the preface of the book in question.

TRANSACTIONS THIRD WORLD POWER CONFERENCE, 1936. Ten Volumes, edited by O. C. Merrill, Washington, D. C., World Power Conference, Superintendent of Documents, 1938. Volume I, 423 pages; Volume II, 700 pages; Volume III, 688 pages; Volume IV, 575 pages; Volume V, 696 pages; Volume VI, 806 pages; Volume VII, 787 pages; Volume VIII, 825 pages; Volume IX, 809 pages; Volume X, 897 pages, illustrated, 10 by 6 inches, cloth, $2.50 per volume; $22.00 per set of ten volumes; 25 per cent discount for 100 volumes or more in a single order. These ten volumes contain a full record of the meetings of the third conference, held in Washington, 1936. Its theme was "The national power economy; its physical and statistical basis; its technical, social, and economic trends; the relation thereto of the fuel producing, processing, and distributing industries and the electric and gas utilities; practices and policies respecting organization, control, and public regulation; national and regional planning of power development and use; conservation of fuel and water resources; rationalization of the distribution of gas and electricity; and national power and resources policies." Thirty-one countries submitted reports upon one or more of the 18 topics considered.

ENGINEERING OPPORTUNITIES. Edited by R. W. Clyne; foreword by K. T. Compton. New York and London, D. Appleton-Century Company, 1939. 307 pages, illustrated, 8 by 6 inches, cloth, $3.00. Twenty-six engineering opportunities are described in this non-technical survey of engineering activities in industry. The authors of the various chapters show in each case the industry's background, present condition, and future possibilities.

AIR-CONDITIONING ENGINEERS' ATLAS. By C. Strock and C. H. B. Hotchkiss. New York, Industrial Press, 1939. 72 pages, maps, 12 by 9 inches, cloth, $2.00. Presents in condensed and readily usable form the weather data needed by engineers in solving problems of heating and cooling. Eighteen maps of the United States, colored in zones, show the various phases of summer and winter weather which concern the heating industry. Supplementary tables give the data for the larger cities.

DIESEL HAND BOOK. By J. Rosbloom. Sixth edition. Jersey City, Diesel Engineering Institute, 1939. 720 pages, illustrated, 7 by 5 inches, leather, $5.00. This manual for operators presents fundamentals in simple language. Engine details and auxiliaries and their action are described; the principal American types of engines are presented; and practical advice is given on operation, adjustment, and maintenance. Contains questions and answers for license examinations for both marine and land service.

ELECTRICAL ENGINEERING EXPERIMENTS, THEORY AND PRACTICE. By H. R. Reed and G. F. Corcoran. New York, John Wiley and Sons, 1939. 500 pages illustrated 9½ by 6 inches, cloth, $4.50. A textbook designed for electrical engineering laboratories. Contains an introduction and seven sections: fundamentals, d-c machines, a-c circuits, transformers, synchronous machines, induction machines, and electronics. With each experiment are included pertinent theory, laboratory exercises, and possible results.

ELECTRON OPTICS, THEORETICAL AND PRACTICAL. By L. M. Myers. New York, D. Van Nostrand Company, 1939. 618 pages, illustrated, 9 by 6 inches, cloth, $12.00. Recent improvements in vacuum technique have brought to a practical point certain applications of electron behavior, the relation of which to the science of geometric optics is discussed in this book. Includes chapters on analogies between light and electrons, the electron trajectory, electron lenses and aberrations, the electron multiplier, vacuum technique, the electron microscope, and further applications. Said to be the first work in English on this branch of vacuum physics.

THEORETICAL AND APPLIED ELECTROCHEMISTRY. By M. de K. Thompson. Third edition. New York, The Macmillan Company, 1939. 535 pages, illustrated, 9 by 6 inches, cloth, $5.00. This textbook contains a treatise on theoretical electrochemistry for the electrochemical engineer and accounts of the most important electrochemical industries and the principal applications of electrochemistry in the laboratory. Includes references for detailed descriptions.

Engineering Societies Library

39 West 39th Street, New York, N. Y.

MAINTAINED as a public reference library of engineering and the allied sciences, this library is a co-operative activity of the national societies of civil, electrical, mechanical, and mining engineers.

Resources of the library are available also to those unable to visit it in person. Lists of references, copies or translation of articles, and similar assistance may be obtained upon written application, subject only to charges sufficient to cover the cost of the work required.

A collection of modern technical books is available to any member residing in North America at a rental rate of five cents per day per volume, plus transportation charges.

Many other services are obtainable and an inquiry to the director of the library will bring information concerning them.

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(Terms expire July 31, 1942)

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Santa Clara, Univ. of, Santa Clara, Calif.	8	B. F. Peterson
South Carolina, Univ. of, Columbia	4	T. F. Ball
South Dakota State Col., Brookings	6	W. H. Gamble
So. Dak. State Sch. of Mines, Rapid City	6	J. O. Kammerman
Southern California, Univ. of, Los Angeles, Calif.	8	W. G. Angermann
Southern Methodist Univ., Dallas, Texas	7	S. G. Lutz
Stanford Univ., Stanford University, Calif.	8	H. H. Skilling
Stevens Inst. of Tech., Hoboken, N. J.	3	H. C. Roters
Swarthmore Col., Swarthmore, Pa.	2	J. D. McCrumm
Syracuse Univ., Syracuse, N. Y.	1	C. W. Henderson
Tennessee, Univ. of, Knoxville	4	J. G. Tarboux
Texas A. & M. Col., College Station	7	H. C. Dillingham
Texas Technological Col., Lubbock	7	C. V. Bullen
Texas, Univ. of, Austin	7	
Tufts Col., Tufts College, Mass.	1	B. A. Walker
Tulane University, New Orleans, La.	4	M. G. Zervigon
Union Col., Schenectady, N. Y.	1	
Utah, Univ. of, Salt Lake City	9	A. L. Taylor
Vermont, Univ. of, Burlington	1	R. R. McKee
Villanova Col., Villanova, Pa.	2	H. S. Bueche
Virginia Military Inst., Lexington	4	J. S. Jamison
Virginia Poly. Inst., Blacksburg	4	Claudius Lee
Virginia, Univ. of, University	4	L. R. Quarles
Washington, State Col. of, Pullman	9	H. F. Lickey
Washington, Univ. of, Seattle	9	R. R. Lindblom
Washington Univ., St. Louis, Mo.	7	H. G. Hake
West Virginia Univ., Morgantown	2	A. H. Forman
Wisconsin, Univ. of, Madison	5	R. R. Benedict
Worcester Poly. Inst., Worcester, Mass.	1	V. Siegfried
Wyoming, Univ. of, Laramie	6	G. H. Sechrist
Yale Univ., New Haven, Conn.	1	A. G. Conrad

Total 121

Local Sections of the Institute

Name	District	When Organized	Membership Aug. 1, 1939	Chairman	Secretary	Secretary's Address
Akron	2	Aug. 12, '20	75	T. F. Brandt	F. W. Nimmer	Ohio Edison Co., Akron, Ohio
Alabama	4	May 22, '29	31	W. W. Hill	T. H. Mawson	Commonwealth & Southern Corp., Birmingham, Ala.
Boston	1	Feb. 13, '03	414	J. C. Balsbaugh	J. M. Murray	Simplex Wire & Cable Co., 79 Sidney St., Cambridge, Mass.
Central Indiana	5	Jan. 12, '12	126	J. G. Harden	R. A. Scholl	Northern Indiana Pwr. Co., 110 No. Illinois St., Indianapolis, Ind.
Chicago	5	1893	733	A. J. Krupy	P. V. Smith	Sargent & Lundy, 140 So. Dearborn St., Chicago, Ill.
Cincinnati	2	June 30, '20	180	M. S. Schneider	V. G. Rettig	Cincinnati Gas & Elec. Co., 327 Plum St., Cincinnati, Ohio
Cleveland	2	Sept. 27, '07	298	H. J. Dible	J. C. Strasbourger	Cleveland Elec. Ill. Co., 75 Public Square, Cleveland, Ohio
Columbus	2	Mar. 17, '22	95	F. W. Atkinson	N. J. Greene	National Electric Coil Co., Columbus, Ohio
Connecticut	1	Apr. 16, '21	265	R. S. Judd	A. G. Conrad	Yale University, New Haven, Conn.
Dallas	7	May 18, '28	140	C. W. Mier	H. R. Pearson	Dallas Power & Light Co., Engg. Dept., Dallas, Texas
Denver	6	May 18, '15	182	R. H. Owen	John R. Walker	U. S. Bureau of Reclamation, Denver, Colo.
East Tennessee	4	Sept. 2, '36	118	K. E. Hapgood	W. G. Parrott, Jr.	Tennessee Elec. Power Co., 417 Power Bldg., Chattanooga, Tenn.
Erie	2	Jan. 11, '18	65	F. H. Craton	W. D. Bearce	4121 Sassafras St., Erie, Pa.
Florida	4	Jan. 28, '31	73	J. C. Jones	Joseph Weil	University of Florida, Gainesville, Fla.
Fort Wayne	5	Aug. 14, '08	98	F. H. Fleischer	C. R. Atkinson	General Electric Co., 1635 Broadway, Fort Wayne, Ind
Georgia	4	Jan. 14, '04	104	J. O'D. Shepherd	J. M. Flanigen	Georgia Power Co., Atlanta, Ga.
Houston	7	Aug. 7, '28	139	T. M. Keiller	L. H. Matthes	Box 2870, Beaumont, Texas
Iowa	5	June 25, '29	67	H. W. Anderson	G. F. Corcoran	State University of Iowa, Elec. Engg. Dept., Iowa City, Iowa
Ithaca	1	Oct. 15, '02	51	True McLean	J. P. Wood	Cornell University, Ithaca, N. Y.
Kansas City	7	Apr. 14, '16	125	L. L. Davis	E. J. Karsten	P. O. Box 679, Kansas City, Mo.
Lehigh Valley	2	Apr. 16, '21	191	S. S. Seyfert	J. E. Treweek	Pennsylvania Power & Light Co., Hazleton, Pa.
Los Angeles	6	May 19, '08	433	M. A. Sawyer	F. C. Lindvall	California Institute of Technology, Pasadena, Calif.
Louisville	4	Oct. 15, '26	56	J. M. Houchens	J. F. Miller	Louisville Gas & Elec. Co., Louisville, Ky.
Lynn	1	Aug. 22, '11	145	C. F. Savage	J. W. Lingary	Lynn Gas & Electric Co., 788 Broad St., West Lynn, Mass.
Madison	5	Jan. 8, '09	65	W. A. Kuehlthau	H. J. Kubiak	University of Wisconsin, Elec. Lab., Madison, Wis.
Mansfield	2	Mar. 6, '39	64	H. F. Herbig	H. N. Diller	Ohio Public Service Co., Mansfield, Ohio
Maryland	2	Dec. 16, '04	224	H. A. Frey	G. R. Page	Western Electric Co., Point Breeze Works, Baltimore, Md.
Memphis	4	May 23, '30	61	G. F. Leake	A. H. Murrell	Memphis Power & Light Co., 178 Walnut St., Memphis, Tenn.
Mexico	3	June 29, '22	56	C. Santacruz	C. C. Jagou	Apartado 2966, Mexico City, Mexico
Michigan	5	Jan. 13, '11	358	W. G. Knickerbocker	R. V. Sayles	Commonwealth & Southern Corp., Jackson, Mich.
Milwaukee	5	Feb. 11, '10	270	L. T. Rosenberg	R. H. Earle	206 North 85th St., Wauwatosa, Wis.
Minnesota	5	Apr. 7, '02	89	I. B. Garthus	K. J. Mertz	Northern States Power Co., St. Paul, Minn.
Montana	9	June 24, '31	39	C. F. Bowman	W. A. Boyer	2921 Edwards St., Butte, Mont.
Muscle Shoals	4	Feb. 18, '38	46	W. M. Stanley	H. R. Nelson	Box 511, Guntersville Dam, Ala.
Nebraska	6	Jan. 21, '25	56	O. E. Edison	C. F. Holdrege	327 North 41st Ave.; Omaha, Neb.
New Orleans	4	Dec. 8, '33	97	L. L. Newman	F. E. Johnson	317 Baronne St., New Orleans, La.
New York	9	Dec. 10, '19	3,355	George Sutherland	D. A. Quarles	Bell Telephone Labs., Inc., 463 West St., New York, N. Y.
Niagara Frontier	1	Feb. 10, '25	201	G. M. Pollard	J. H. Milbyer	Buffalo Niagara Elec. Corp., 300 Electric Bldg., Buffalo, N. Y.
North Carolina	4	Mar. 21, '29	85	R. S. Fouraker	V. R. Parrack	Carolina Power & Light Co., Raleigh, N. C.
Oklahoma City	7	Feb. 16, '22	120	C. E. Bathe	John Shawver	Oklahoma Gas & Electric Co., Oklahoma City, Okla.
Philadelphia	2	Feb. 18, '03	610	E. P. Yerkes	W. B. Morton	Philadelphia Electric Co., Edison Bldg., Philadelphia, Pa.
Pittsburgh	2	Oct. 13, '02	517	E. W. Oesterreich	G. R. Patterson	Carnegie Institute of Technology, Pittsburgh, Pa.
Pittsfield	1	Mar. 25, '04	178	C. A. Read	M. B. Scoville	General Electric Co., Pittsfield, Mass.
Portland	9	May 18, '09	151	Corbett McLean	J. A. Hooper	Northwestern Elec. Co., Public Service Bldg., Portland, Ore.
Providence	1	Mar. 12, '20	91	W. B. Hall	O. E. Sawyer	56 Friendly Road, Auburn, R. I.
Rochester	1	Oct. 9, '14	95	C. E. Tuites	W. F. Cotter	Stromberg-Carlson Tel. Mfg. Co., Rochester, N. Y.
St. Louis	7	Jan. 14, '03	268	R. S. Glasgow	R. H. Baxter	Southwestern Bell Tel. Co., 1330 Telephone Bldg., St. Louis, Mo.
San Antonio	7	May 23, '30	43	Bro. L. P. Thein	Eugene Bissett	San Antonio Public Service Co., Box 1771, San Antonio, Texas
San Diego	8	Jan. 18, '39	30	F. F. Evenson	C. J. Nevitt	San Diego Consolidated Gas & Elec. Co., San Diego, Calif.
San Francisco	8	Dec. 23, '04	486	A. A. Andrews	M. S. Barnes	General Electric Co., 804 Russ Bldg., San Francisco, Calif.
Saskatchewan	10	Oct. 14, '25	21	P. E. Kirkpatrick	M. S. Haynes	Balfour Technical School, Regina, Sask., Canada
Schenectady	1	Jan. 26, '03	403	C. W. LaPierre	O. C. Rutledge	General Electric Co., Works Lab., Schenectady, N. Y.
Seattle	9	Jan. 19, '04	153	C. J. Hawkes	A. I. Launder	Pacific Tel. & Tel. Co., 1200—3rd Ave., Seattle, Wash.
Sharon	2	Dec. 11, '25	86	E. Steinert	C. L. Knotts	Westinghouse Elec. & Mfg. Co., Sharon, Pa.
Spokane	9	Feb. 14, '13	62	Neal Baden	G. L. Lane	Washington Water Power Co., 825 Trent Ave., Spokane, Wash.
Springfield	1	June 29, '22	60	R. E. Curtis	H. D. Griffith	Westinghouse Elec. & Mfg. Co., Springfield, Mass.
Syracuse	1	Aug. 12, '20	71	C. W. Henderson	E. A. Gruppe	523 E. Genesee St., Fayetteville, N. Y.
Toledo	2	June 3, '07	78	J. S. Sawvel	W. M. Campbell	Toledo Edison Co., Toledo, Ohio
Toronto	10	Sept. 30, '03	338	D. G. Geiger	F. C. Barnes	Canadian General Electric Co., Ltd., 212 King St., W., Toronto
Tulsa	7	Oct. 1, '37	107	A. L. Jones	H. P. Dougherty	Southwestern Bell Telephone Co., Tulsa, Okla.
Urbana	5	Nov. 25, '02	77	G. H. Fett	C. A. Schille	Illinois Iowa Power Co., Champaign, Ill.
Utah	9	Mar. 9, '17	76	F. E. Young, Jr.	A. C. Kelm	Utah Power & Light Co., Salt Lake City, Utah
Vancouver	10	Aug. 22, '11	107	G. K. Haspel	T. F. Hadwin	B. C. Electric Railway Co. Ltd., Vancouver, B. C., Canada
Virginia	4	May 19, '22	94	F. W. Smith	L. Saunders	1042 Jamestown Crescent, Norfolk, Va.
Washington	2	Apr. 9, '03	332	R. W. Prince	F. B. Crider	806—15th St., N. W., Washington, D. C.
Wichita	7	Sept. 16, '37	46	W. J. Knightley	R. B. Gow	Kansas Gas & Electric Co., Wichita, Kansas
Worcester	1	Feb. 18, '20	58	R. H. Bryant	W. W. Locke	Worcester Polytechnic Institute, Worcester, Mass.
Total	67					

Transactions

Papers and Discussions Comprising Pages 435–98 of the 1939 Volume

Temperature Aging Characteristics of Class A Insulation

J. J. SMITH
ASSOCIATE AIEE

J. A. SCOTT
MEMBER AIEE

Synopsis: This paper reviews the literature relating to the effect of temperature on the life of class *A* insulation. It presents test data on aging of built-up samples 100 mils thick, of varnished cloth, both black and yellow, over the temperature range 105 to 200 degrees centigrade.

The effect of temperature on the insulation was measured by three different methods—physical condition by visual observation, bending of the insulation to produce cracking, and the lowering of the breakdown voltage of samples which had been immersed in water. The final results are given in the form of temperature-time curves for several degrees of deterioration as measured by each of the tests.

THE materials used for insulation purposes in electric machines are subject to many factors which determine their useful life. They are subject to the effects of temperature, of mechanical stresses, vibration, electrical stresses, to the effect of oil in oil-filled apparatus, to moisture, dirt, and in some cases corrosive gases. Past experience shows that the life of a machine may be limited by any of these causes, and engineers must make proper allowance for each of them in design.

The importance of the effects of temperature was recognized early and definite limits were agreed upon for the maximum permissible operating temperatures which would constitute good practice for the various types of insulation used. These limiting values were based upon the knowledge of materials available at that time, and the performance of electric apparatus built to conform with these values has shown excellent results.

Since that time the electrical industry has made considerable progress. In addition, the chemical industry has been producing at a very rapid rate new materials which electrical engineers have been carefully studying as promising candidates to supplement or supplant the older forms of insulation.

It therefore is desirable to review briefly the previous work and compare the results in service with expectations on the basis of operating temperatures and with the results of later laboratory tests. Also, from these comparisons it is desirable to examine the latter and determine their significance.

Previous Work

In 1905 a paper by E. H. Rayner[1] in the *Journal* of the Institution of Electrical Engineers discussed the effect of temperature on insulation, pointing out the rapid effects of high temperatures on life. However, no very definite conclusions as to permissible temperatures were drawn.

In 1913 the Institute held a symposium[2] on the subject at which a number of papers were presented and much discussion ensued. The assumption was made that class *A* insulation had a ten-year useful service life at 100 degrees centigrade and one indefinitely long at 90 degrees centigrade, but one of only a few weeks at 125 degrees centigrade. Two ideas will be found in this discussion—one that as high a temperature as possible should be permitted, consistent with reasonable life of the machine, the other the importance of reliability in the operation of the machines and, therefore, the desirability of not departing greatly from the operating temperatures which were actually in use at that time. Following this discussion AIEE Standard No. 1 was evolved which recommended for purposes of standardization the following limiting "hot spot" temperatures for electrical machinery and apparatus:

Class *A* material (treated organic)	105 degrees centigrade
Class *B* material (inorganic, plus binder)	125 degrees centigrade
Class *C* material (pure inorganic)	Not set

In the intervening years laboratory confirmation was undertaken, and a large amount of testing has been carried out by various groups. Experience in the development, design, and performance of apparatus has been a most important factor.

Transformer engineers made aging tests on insulation under oil which have formed the basis of V. M. Montsinger's eight-degree rule.[3] This rule states that the rate of deterioration of oil-immersed varnished cloth doubles for every eight-degree-centigrade increase in temperature. In the same paper Mr. Montsinger states that the rate of deterioration is less for aging in air than in oil, and in his figure 9 gives two dotted curves for air which correspond in slope respectively to 13 degrees and 26 degrees centigrade in-

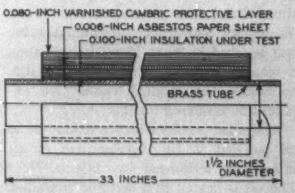


Figure 1. Test sample for aging class A insulation

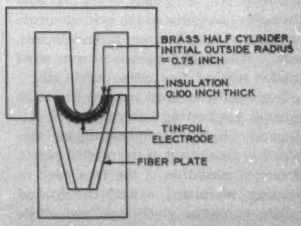


Figure 2. Cracking-on-bending test, showing fixture for bending semicylindrical sample

Paper number 39-7, recommended by the AIEE committee on electrical machinery, and presented at the AIEE winter convention, New York, N. Y., January 23–27, 1939. Manuscript submitted October 21, 1938; made available for preprinting November 29, 1938.

J. J. SMITH and J. A. SCOTT are in the general engineering laboratory of the General Electric Company, Schenectady, N. Y.

1. For all numbered references, see list at end of paper.

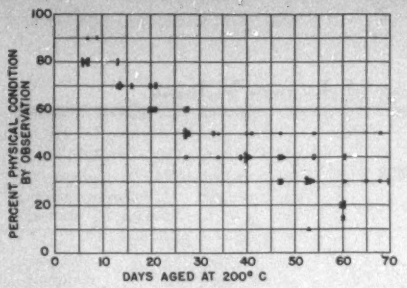

△—Black varnished cloth
⊙—Yellow varnished cloth
⊡—Cotton tape and black varnish
PERCENT PHYSICAL CONDITION BY OBSERVATION
DAYS AGED AT 200° C

Figure 3

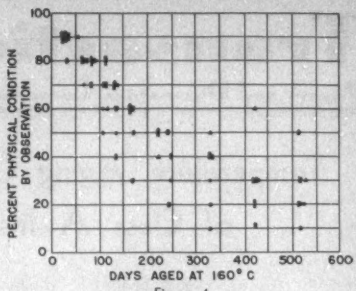


Figure 4

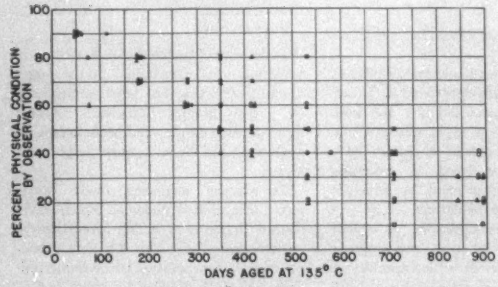


Figure 5

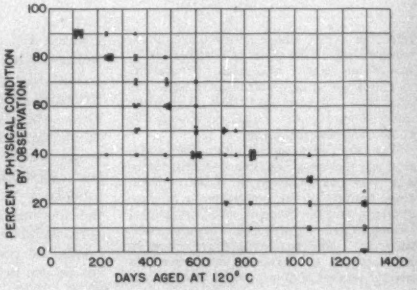


Figure 6

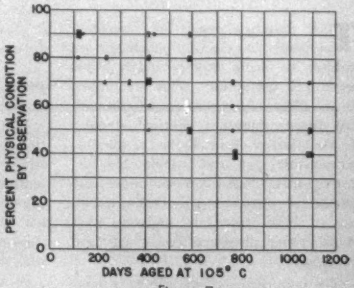


Figure 7

Figures 3–7. Physical condition by observation of class A insulation samples aged for various periods of time at 200, 160, 135, 120, and 105 degrees centigrade in ovens

crease in temperature for half the life.

At Massachusetts Institute of Technology three extensive series of tests[6] on oil-treated cable paper aged in oil as short lengths of cable showed that the mechanical properties deteriorated with time of test, but at temperatures below 90 degrees centigrade a minimum value was reached in 20 to 28 weeks and then a recovery brought the insulation back to nearly the original value. No explanation is offered for this.

A similar problem in the oxidation of oil has led to the development of an interesting technique by Dornte.[12,13,14] The oil is heated in a suitable container and oxygen bubbled through it. The number of cubic centimeters of oxygen absorbed per 100 grams of oil per hour then gives an index of the oxidation rate or aging of the oil at any given temperature. Whitehead[15] has used a somewhat similar method for testing cable oils.

Investigational work carried on in the general engineering laboratory of the General Electric Company during this period is the subject of the present paper. It covers insulation of the type used in rotating machines, namely black and yellow varnished cloth tape and white cotton tape dipped in varnish. Suitable structures with these insulations were aged in air at five temperatures between 100 degrees and 200 degrees centigrade.

Method of Measuring Aging

The criterion for the service life of the insulation of a machine is failure. If this is definitely caused by operation at uniform and long-continued high temperatures, it may safely be said that it gives a measure of the life of that insulation at that temperature for that kind of apparatus and service. In testing the life of insulation in the laboratory it has been impractical to test completed assemblies in the large numbers required to give reliable results. The total number of test specimens used in the present work was 600. Thus it becomes necessary to make tests on the material itself dissociated from the structure. In such tests some definite property of the material is selected and measured periodically after aging at several different temperatures, thus determining for these temperatures a characteristic aging curve for that property. In order to use such laboratory results to estimate the useful life of the insulation under service conditions it is necessary to select some definite deterioration in the measured property as its limit of serviceableness. It is as-

sumed that when it has reached this condition, its useful life is ended.

Properties which may be measured include the following:

Insulation resistance
Electric breakdown
Power factor and dielectric power loss
Physical condition by visual observation
Cracking on bending (radius of bend to produce cracking)
Flexibility
Tensile strength
Folding endurance

The first three are electrical tests and the last five are mechanical tests.

In the present study, tests of the first five types were included. The observations of the physical condition of the insulation (figures 3 to 7) and cracking on bending (figures 8 to 12) show a continuous deterioration due to aging at all temperatures. The electrical properties improved in some cases with aging. For example, the insulation resistance increased as the test progressed, as might be expected due to the evaporation of moisture. The power factor of samples aged at 135 degrees centigrade decreased at first and then increased, as shown in figure 18. The breakdown voltage of the samples tested after immersion in water, given in figures 13 to 17, decreased fairly uniformly over the period of aging.

The criterion used by Montsinger[2] in his work on aging of paper in oil was tensile strength. The resulting curves given in his paper are quite consistent. Folding endurance tests were used in the studies[6] made at Massachusetts Institute of Technology. The results show the insulation aged progressively with time up to a certain point and then recovered. These two latter types of test were not adaptable to the test structure used in the present work, but it is interesting that different observers arrived independently at the greater usefulness of the mechanical test results.

Test Specimen and Aging Procedure

Since it was desired that the tests should typify deeply embedded class *A* insulation as used in motor and generator slots, the test specimen was designed in order to simulate as far as possible such insulation conditions.

Six-hundred samples were used consisting of a 100-mil thickness of the insulation wrapped on a brass tube $1^1/_2$ inches in diameter and 33 inches long, as shown in figure 1. In order to exclude direct contact with the ambient air during the aging tests this insulation was protected by a 0.006-inch layer of asbestos paper and an additional 0.080-inch layer of varnish tape. The purpose of such protection was twofold. First, it was considered that in an actual machine the outer layers of insulation are the coolest and serve to protect the inner layers which, being the hottest, age most rapidly. Second, for laboratory tests it was desirable that the insulation age as uniformly as possible throughout its mass in order to get consistent results which might in turn be used with

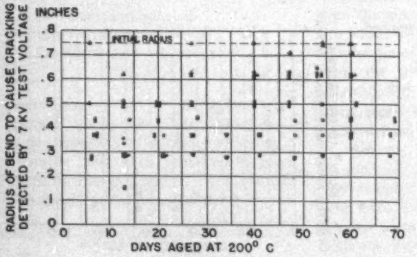


Figure 8

△—Black varnished cloth
⊙—Yellow varnished cloth
⊡—Cotton tape and black varnish

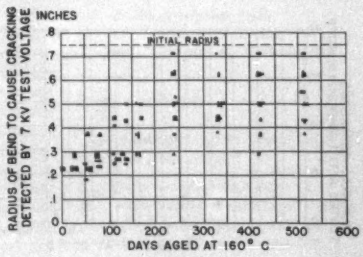


Figure 9

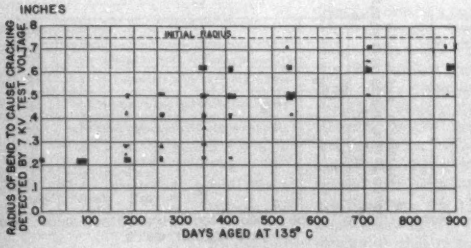


Figure 10

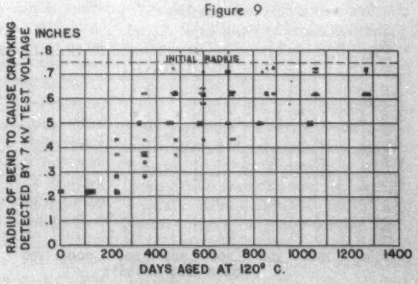


Figure 11

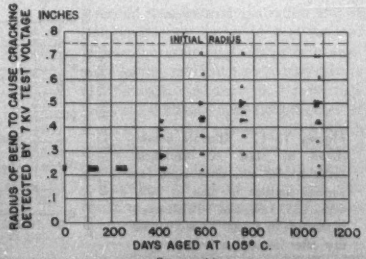


Figure 12

Figures 8–12. Radius of bend to cause cracking detected by seven-kv test voltage of class A insulation samples aged for various periods of time at 200, 165, 135, 120, and 105 degrees centigrade in ovens

other data to allow for the difference in temperature of the various layers or other conditions in an actual machine.

This choice of deeply embedded insulation and the fact that the tests were carried out in air restricted the type of test criterion. For example, tensile strength or other similar mechanical tests could not be made on the aged tapes since the entire thickness of insulation hardens during aging into a dry mass that will not permit the tapes to be unwound without tearing.

Three kinds of insulation were used in these tests:

A. Black varnished cloth tape
B. Yellow varnished cloth tape
C. White cotton tape treated by successively baked dips of black varnish

The tube samples were placed in ovens while the tests conducted at 120 degrees centigrade extended almost 4 years.

Electrical Tests

The electrical tests of insulation resistance, breakdown voltage, and dielectric loss and power factor were made in the usual manner on (*a*) dry tubes as taken from the oven and cooled to room temperature, (*b*) wet tubes, soaked in tap water for 48 hours on removal from the oven.

Mechanical Tests

The mechanical tests were physical condition by visual observation, and cracking on bending.

The tests for physical condition were made by a personal observation of four samples at each test period. An expert can estimate the degree of deterioration very closely by the general appearance, breaking and rubbing small pieces with the fingers, scratching with thumb nail, etc. The chief objection to this method is the personal element involved. Where samples of different types are to be compared and classified, there is an unconscious tendency to favor those types which the examiner had previously believed to be the best. It is also very difficult to classify correctly a large number of samples unless some systematic method is followed.

With this in mind a system of classification was devised. It aims toward eliminating the personal element as far as possible and reducing the results to the simplest terms. Samples were not selected for examination in the order of

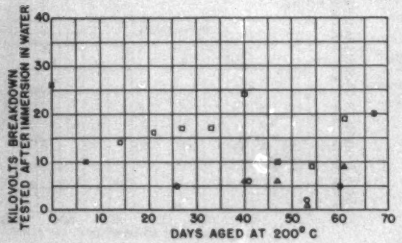


Figure 13

△—Black varnished cloth
⊙—Yellow varnished cloth
⊡—Cotton tape and black varnish

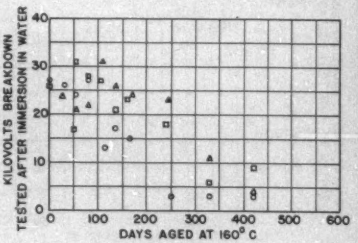


Figure 14

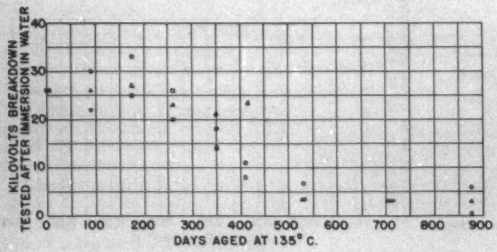


Figure 15

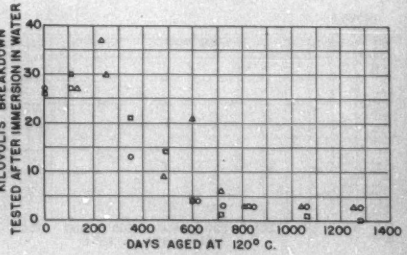


Figure 16

and held at the following temperatures: 200, 160, 135, 120, and 105 degrees centigrade. Once each week the heat was shut off for six hours and the oven doors opened to allow the samples to cool to room temperature and undergo the expansion and contraction that is encountered in actual operation in machines.

Samples were taken from the oven according to the schedule listed in table I. The 200-degree-centigrade tests were completed in about 2 months, the 160-degree-centigrade tests ran 18 months,

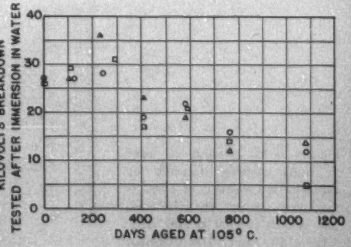


Figure 17

Figures 13–17. Kilovolt breakdown of class A insulation samples 100 mils thick aged for various periods of time at 200, 165, 135, 120, and 105 degrees centigrade in ovens. Tested wiped dry after immersion in tap water for 48 hours

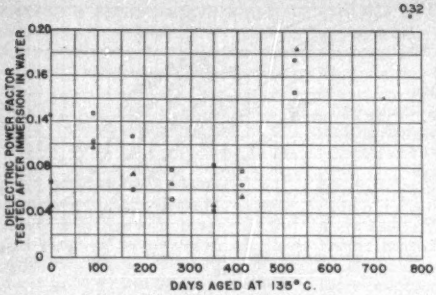


Figure 18. Dielectric power factor of class A insulation samples aged for various periods of time at 135 degrees centigrade in ovens. Tested wiped dry after immersion in tap water for 48 hours

△—Black varnished cloth
⊙—Yellow varnished cloth
⊡—Cotton tape and black varnish

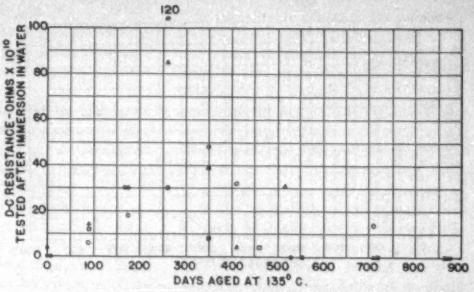


Figure 19. Insulation resistance of class A insulation samples aged for various periods of time at 135 degrees centigrade in ovens. Tested wiped dry after immersion in tap water for 48 hours

△—Black varnished cloth
⊙—Yellow varnished cloth
⊡—Cotton tape and black varnish

their aging period or type, but were selected at random. The "lining up" of the classification or rating with length of aging time then furnished a good check on the judgment of the examiner. The classification was as follows:

Per Cent Rating	Physical Condition by Visual Observation
100	Fresh, soft, and flexible (still tacky)
90	Dry but still soft and flexible
80	Dry but still flexible (hardening)
70	Dry and hard but still retaining flexibility
60	Hard and compact with very slight flexibility
50	Hard, compact, and inflexible but not exactly brittle
40	Brittle but compact and without checks
30	Brittle with checks forming
20	Brittle, checked, and partly cracked (slightly crumbly)
10	Badly cracked and crumbly (partly charred)
0	Completely cracked, charred, and crumbly

The above system of rating applies only to samples protected from exposure to air during the aging process by protective wrappings, which are removed before final tests are made. The total thickness of such insulation samples deteriorates uniformly and closely represents the inner wrappings of coil insulation where the "hot spot" occurs. When samples are exposed directly to air in an oven, the outer wrappings deteriorate faster than the inner, and a percentage rating would be very difficult to make.

Table I

Temperature at Which Samples Were Aged (Deg C)	Time in Days at Which Tests Were Made
200 (run 1)	7, 14, 20, 27, 40, 47, 54, 61
200 (run 2)	8, 14, 20, 27, 34, 41, 47, 54, 61, 68
160	27, 54, 81, 108, 136, 169, 243, 331, 419, 514
135	88, 176, 263, 350, 413, 531, 707, 877
120	114, 236, 350, 479, 600, 714, 825, 1,053, 1,283
105	114, 236, 413, 586, 761, 1,085

The test to determine the amount of cracking on bending was as follows: Six good half sections were cut from the tube samples for bending test. These were seven inches long and semicircular in cross section and included both the thickness of insulation to be tested and the section of brass tubing directly under it, having a normal radius of 0.75 inch. Using vaseline as a paste, a strip of metal foil was applied five inches long and three-quarters-inch wide in the center of the outer surface area. The section of brass tubing served as the ground electrode and the strip of foil as high-voltage electrode in the test which followed. The sample was placed in a bending machine (see figure 2) and bent from the normal tube radius of 0.75 inch until it coincided with a templet having a minimum radius of 0.71 inch. Holding the sample at this radius, seven kv* was applied for one minute. If the sample did not fail, it was bent to the shape of a second templet having a radius of 0.62 inch and seven kv again held for one minute. Continuing in steps with templets having minimum radii respectively of 0.50 inch, 0.43 inch, 0.37 inch, 0.29 inch, and 0.22 inch until sample failed at seven kv, a radius was determined which produced cracking. Five additional samples were tested and the results averaged. The radius at which this cracking occurred was used as the index of cracking on bending.

* The normal breakdown of these tubes when new would be 30 kv approximately.

Results of Tests

As mentioned before, three kinds of insulation were tested:

A. Black varnished cloth tape
B. Yellow varnished cloth tape
C. White cotton tape treated by successively baked dips of black varnish

To secure a more reliable trend the data for all three kinds of insulation tested, namely black varnished cloth, yellow varnished cloth, and cotton tape treated with varnish, were consolidated. As these are all of the same genera' class there was more advantage to be gained by combining the data than to attempt separate analysis. However, in all the figures these materials are indicated by separate codes, triangles, circles, and squares respectively representing black varnished cloth, yellow varnished cloth, and cotton tape treated with black varnish.

The complete plots of physical condition are presented in graphic form as follows:

Figure 3. Physical condition–days aged at 200 degrees centigrade

Figure 4. Physical condition–days aged at 160 degrees centigrade

Figure 5. Physical condition–days aged at 135 degrees centigrade

Figure 6. Physical condition–days aged at 120 degrees centigrade

Figure 7. Physical condition–days aged at 105 degrees centigrade

These curves show a definite reduction in the physical condition by observation

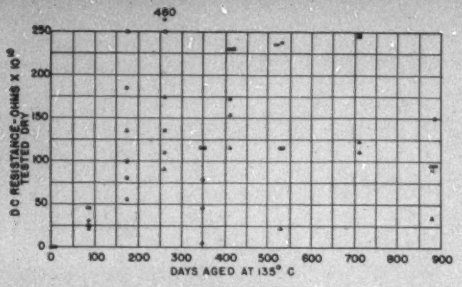


Figure 20. Insulation resistance of class A insulation samples aged for various periods of time at 135 degrees centigrade in ovens. Tested dry

△—Black varnished cloth
⊙—Yellow varnished cloth
⊡—Cotton tape and black varnish

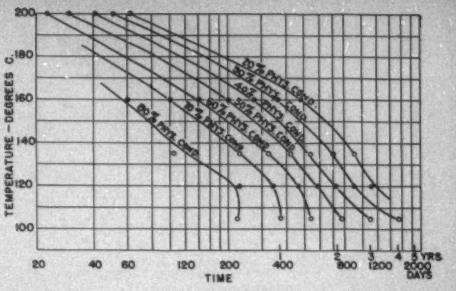


Figure 21. Curves showing the relation for class A insulation between temperature and time of aging to produce various physical conditions as determined by observation

as the aging progresses. Also, the higher the temperature the more rapid the deterioration to any given condition and hence the shorter the life. While the points are scattered, fairly representative average values can be obtained on account of the large number of samples used. The intersection of these average curves with the ordinate for any per cent physical condition gives the time required for the insulation to reach that condition at that temperature. It should be noted, of course, that the per cent physical condition represents the arbitrary evaluation previously given and there is not necessarily the definite relation between the conditions which the numbers would indicate. Nevertheless, on account of the number of conditions used, any resulting errors tend to be minimized as may be seen from the curves.

The complete plots of the results of the cracking on bending test are presented in graphic form as follows:

Figure 8. Radius of bend–days aged at 200 degrees centigrade

Figure 9. Radius of bend–days aged at 160 degrees centigrade

Figure 10. Radius of bend–days aged at 135 degrees centigrade

Figure 11. Radius of bend–days aged at 120 degrees centigrade

Figure 12. Radius of bend–days aged at 105 degrees centigrade

These curves show that when nearly new, the insulation wall may be bent from its initial radius of 0.75 inch to almost 0.2 inch before cracking occurs for an aging temperature of 105 degrees centigrade, but that when aged upward of 1,200 hours, it may crack when deformed only slightly to 0.71 inch. At 120 degrees centigrade the upward drift of the radius at which cracking occurs is more clearly shown as at this temperature the test time was long enough to show definitely the life by cracking. The other higher temperatures show similar trends. A comparison of the curves shows that the higher the temperature the shorter the time to cause cracking at any given radius of bend and thus the shorter the life. The points in these diagrams are also scattered, but again fairly representative values can be obtained due to the large number of samples used. The results at 200 degrees centigrade show quite a spread and emphasize some of the difficulties attendant on too highly accelerated tests carried out at extreme temperatures.

The complete plots of the results of kilovolt breakdown taken on samples previously immersed 48 hours in water and then wiped dry are presented in graphic form as follows:

Figure 13. Kilovolts breakdown–days aged at 200 degrees centigrade

Figure 14. Kilovolts breakdown–days aged at 160 degrees centigrade

Figure 15. Kilovolts breakdown–days aged at 135 degrees centigrade

Figure 16. Kilovolts breakdown–days aged at 120 degrees centigrade

Figure 17. Kilovolts breakdown–days aged at 105 degrees centigrade

This group of curves shows in general a gradual decrease in breakdown voltage as the period of aging is increased, especially in the case of the samples aged for the longer times at the lower temperatures.

Typical data on insulation resistance and power factor are shown in:

Figure 18. Power factor–days aging at 135 degrees centigrade

Figure 19. Insulation resistance–days aged at 135 degrees centigrade (after immersion in water)

Figure 20. Insulation resistance–days aged at 135 degrees centigrade (dry)

The insulation resistance and power-factor test data were of such a nature that the dependence of the properties on the aging period was not so clearly defined as in the tests for physical conditions, cracking on bending, and kilovolts breakdown after immersion in water. For the purposes of this presentation the discussion has been confined to the results obtained in these last three types of test. Thus, although a complete series of tests was made for each different temperature, only a set of curves taken at 135 degrees centigrade is presented to illustrate the general tendency of the insulation resistance and power factor.

Aging Curves at Various Temperatures

The data on physical condition, cracking on bending, and breakdown voltage after immersion in water were reworked into the form of aging curves at various temperatures.

In the case of physical condition the procedure was as follows: On figures 3 to 7 average curves were drawn through points of average physical condition for a given time of aging. From these average curves the times required for the insulation to reach selected values of physical condition were read. These times were then plotted against the temperature of aging, yielding the curves shown in figure 21.

The procedure for the cracking on bending data was similar. In figures 8 to 12 inclusive average curves were drawn and the time noted at each temperature to reduce the sample to a

condition in which it would have cracked if distorted to a given radius. The resulting curves, figure 22, give the days aging for each temperature to produce cracking on bending for four radii of bend.

For the breakdown-voltage curves the measure of the aging was taken as the time for the breakdown voltage to decrease to arbitrarily selected values. In figures 13 to 17 inclusive, average curves of voltage were drawn and the time estimated at each aging temperature for the breakdown voltage to be reduced to 10 kv and 20 kv. The times required to cause the samples to fail at these voltages are plotted in figure 23.

Figures 21, 22, and 23 summarize the results of these aging tests. They represent the aging time at various temperatures to reach certain conditions of deterioration. They indicate that up to 200 degrees centigrade there is no critical temperature above which the insulation suddenly fails, but that for each temperature there is a definite time required for the insulation to reach a given condition due to heat aging, and that in general the lower the temperature the longer the life.

Comparison of Foregoing Results

For the purpose of comparing the results obtained by the three different methods, that is, physical condition by visual observation, cracking on bending, and kilovolts breakdown, figures 24 and 25 were prepared. The former shows, plotted together, the curves for 60-per-cent physical condition, 30-per-cent physical condition, 0.6-inch radius to produce cracking on bending, and 10-kv breakdown. Figure 25 shows the same data plotted on a logarithmic time scale. It will be noticed that, although each of these three curves has a different basis of selection, they have roughly similar shapes.

The underlying causes of the changes of shape in some of these curves, especially in the region between 110 and 140 degrees centigrade, present an interesting field for study. One of the first effects of heat is to drive off moisture. Continued application of heat may result in a direct chemical change in the molecules of the organic material itself, or a change due to oxidation in the presence of the atmosphere which might not occur in an inert atmosphere. Further changes may then result due to by-products of the oxidation process. To make a scientific study of the temperature aging of insulation these and other variables would require separate investigation. When the variables in the materials themselves are considered as well, it is evident that life-test results must be interpreted with caution.

Discussion of Results

After years of labor involving the most careful preparation of hundreds of test specimens, the maintenance of these at constant temperature in ovens provided with proper temperature distribution for the purpose, the testing of these after aging for various properties, the tabulation of thousands of results, we finally arrive at summary curves as shown in figures 21 to 23.

Some authors[7,11] have proposed rules for calculating the rate of deterioration of insulation as a function of the temperature, such as that the life of the insulation is reduced one-half by each ten-degree-centigrade rise in the operating temperature. The results of the present tests indicate that while such rules may furnish approximations for purposes of simplification in practical applications, due care must be taken to allow for the difference between the actual materials and structures used in the laboratory tests and those of the apparatus under operating conditions. In addition, since the curves show that the rate of deterioration is not constant, too great reliance should not be placed upon short-time tests alone, but they should be supplemented by long-time tests.

At the beginning of the investigation it had been hoped that the work of obtaining such a curve would result in a standard of reference so that as new materials became available they might be tested at higher temperatures to obtain their aging characteristics in a relatively short time, and if these appeared to be outstanding, further investigational work would be carried on toward a more complete evaluation of the material at the lower temperatures. To some extent this objective has been attained, although considerable work is still involved in such tests.

As soon as results are obtained from laboratory tests of any kind there is the immediate urge to correlate them with practical results, and so it has been with these tests. The first reaction is probably a surprise as to the shortness of life as compared with the long life of apparatus in service, but when it is considered that these values are the result of continuous aging at temperatures 105 degrees centigrade and higher, the results are not so startling. In fact, where opportunity has arisen to compare these results with the life of insulation in practice, which was known to have been operated substantially continuously at a given temperature, the correlation has

Figure 22. Curves showing the relation for class A insulation between temperature and time of aging to produce cracking by bending to various radii of curvature

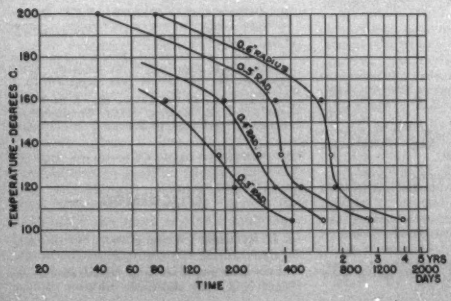
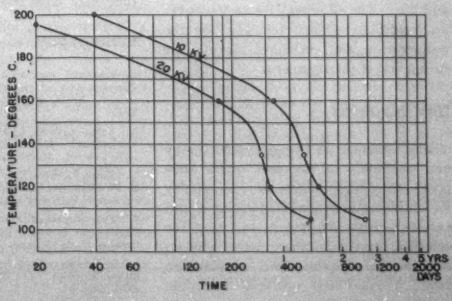


Figure 23. Curves showing the relation for class A insulation between temperature and time of aging to reduce the kilovolts breakdown tested after immersion in water for 48 hours to 10 kv and 20 kv for 100-mil thickness of insulation



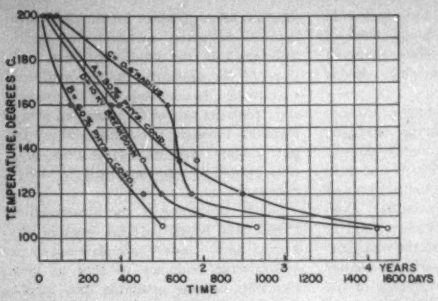


Figure 24. Aging curves of class A insulation, showing the relation between temperature and time of aging

A—Aged to 30-per-cent physical condition

B—Aged to 60-per-cent physical condition

C—Aged to crack on bending to 0.6-inch radius

D—Aged to ten-kv breakdown after immersion in water

Arithmetic scale

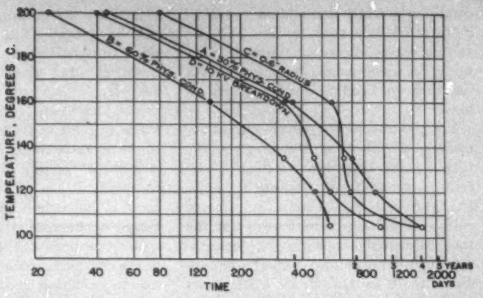


Figure 25. Aging curves of class A insulation, showing the relation between temperature and time of aging

A—Aged to 30-per-cent physical condition

B—Aged to 60-per-cent physical condition

C—Aged to crack on bending to 0.6-inch radius

D—Aged to ten-kv breakdown after immersion in water

Logarithmic scale

been such as to indicate reasonable agreement. Probably the greatest benefit of these aging tests has been to allow design engineers to see the effect of continuous operation at elevated temperatures upon the insulation and to observe the shortness of the resulting life.

Another result of this investigation has been to show the reasonableness of the 105-degrees-centigrade hot-spot temperature for purposes of standardization and for reference since it is quite plain that above this temperature deterioration increases rapidly under continuous operation, whereas below it the indications are from an extrapolation of the curves that the life is long. This value therefore represents the results of engineering judgment based on technical knowledge to obtain optimum service so that full use will be obtained of the insulation strength and life. The allowance for various service conditions is then regulated by the temperature rise measured during the rating test of the apparatus.

New Materials

The advances in bringing forth many new materials in the past years have given to design engineers opportunity for obtaining increased performance, and yet it is probably safe to say that for cellulose materials there has been no fundamental increase in temperature limit. Certain new synthetic materials give opportunity for some increase which can be used to advantage, and it may be that work should be undertaken to classify these materials more directly. It may be satisfactory for their temperature limit to be placed somewhat above that of class *A*, but they surely are not class *B*.

Conclusions

A method of testing the aging of insulation at various temperatures between 105 degrees centigrade and 200 degrees centigrade using carefully constructed laboratory samples has been described. A large number of samples was used. Three different methods of tests were applied. Each method was successful in indicating progressive deterioration of the samples during aging, and the agreement between the results obtained by the three different test methods is also reasonably good. Thus it appears that the methods used may be applied with confidence to the further evaluation of new materials.

The purpose of presenting this material at this time in connection with other papers bearing on the rating of motors run on interrupted duty is to give available data on the effect of temperature on life and to bring forth in discussion from others the data and experience they may have relating to this problem.

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Discussion

J. L. Rylander (Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa.): The paper by J. J. Smith and J. A. Scott is a very desirable addition to the

subject of insulation. Little test data of this kind had been obtained and seldom has any of it been published.

These data are very useful in the consideration of the permissible operating temperatures of electrical machines with class *A* insulation. However, I wish to draw attention to some other features that must be taken into the consideration of safe operating temperatures of machines with class *A* insulation.

It should be noted that these are electrical and mechanical tests on the insulating materials themselves, but not on the motors or generators or even complete windings or coils themselves.

The matter of the design of the windings and all insulation details have a marked effect on the life of the windings at higher temperatures. The weakest detail of insulation determines when the winding fails.

The effect of any temperature above the boiling point of water has a decided effect whenever the insulation has absorbed moisture.

The shrinkage of insulation will often determine the life of many motors and generators. This is most noticeable where there are strong mechanical stresses in the windings due to either centrifugal force or to the stresses due to very heavy currents when starting or at any other time. Shrinkage is noticeable when all of the moisture content is removed from the insulation and this occurs when the boiling point of water is reached.

As stated in the paper there are no formulas for determining the approximate life of windings at various temperatures, but a couple empirical formulas are referred to as having been previously suggested by others. I developed the following formula for my own use from all data that has been available:

$$\text{life} = \frac{K}{(T - A)^3}$$

where K is practically a constant but depends on the general construction or type of winding and T is the operating temperature in degrees centigrade. A is practically a constant but depends upon the kinds and grades of the insulations used. The writer usually uses the value 83 for A. This formula indicates that if you want a motor with class *A* insulation to operate for a very long period such as a hundred years, the maximum temperature would be about 83 degrees centigrade.

P. L. Alger (General Electric Company, Schenectady, N. Y.): There are two highly significant trends in recent insulation developments.

First, there is the development of a multitude of new synthetic materials, whose composition and manufacture are carefully controlled from raw material to finished product. These include the chlorinated hydrocarbons, or Pyranols, for transformers and capacitors, Formex, Glyptal, and other new enamels and varnishes, fiber glass for high temperature insulation, and a vast number of new resins or plastic compounds.

Second, there is the growing use of controlled atmospheres for industrial operations and especially for electrical apparatus. These include hydrogen for rotating machines, nitrogen for transformers and cables, carbon dioxide for explosion-proof motors, sulphur dioxide and Freon for hermetic refrigerator motors, and other gases for high-voltage apparatus.

Both of these trends bring the chemist into the picture, and force the electrical engineer to study chemical reactions, rather than merely physical changes in insulation. There is a basic law of chemical reaction which requires that all chemical changes take place at an accelerated rate as the temperature increases, the rate being approximately double for every ten-degree increase in temperature.

It is, therefore, evident that our future progress will be largely determined by how effectively we bring chemistry to bear on our insulation problems. We must initiate a broad program for development of new insulating materials by chemists. We must ask the chemists to devise new methods of accelerated life tests for these new materials. And, we should ultimately revise our basic standards of temperature rating of apparatus to enable these new materials to be utilized to the fullest degree.

V. M. Montsinger (General Electric Company, Schenectady, N. Y.): I am very much interested in this paper as the authors' work indicates that the rate of change of aging is not constant over the entire range of temperatures from 105 to 200 degrees centigrade. In other words, instead of the rate doubling for a definite number of degrees increase in temperature, it requires an increase of some 20 to 30 degrees in the lower range, and some 10 to 15 degrees in the higher temperature range to double the rate of aging.

It can readily be seen that heavier overloads could be allowed by the curves given in this paper than would result from using the eight-degree rule which we have used in the past.

Until recently, so far as I know, with the exception of L. C. Nichol's work (reference 9), no attempt has been made to estimate to what extent short-time heavy overloads use up the life of the insulation. If a changing rate of aging versus temperature (as indicated in the paper) is used, it becomes practically impossible to integrate the time-temperature areas for short-time overloads. Even when using a simple rule like the eight-degree rule it is no easy task, for the reason that it is difficult to calculate the hottest spot temperature and then to resolve the time-temperature areas into forms suitable for integration.

In most types of rotating machinery, heavy overloads usually are not limited by temperature but by other factors like torque, stalling, commutation, etc. Where the amount of overload is limited for electrical reasons to moderate values, it appears that the effect of overload on the aging of the insulation can be closely approximated by using some simple method like the eight-degree rule.

Last year I had an opportunity to analyze short-time heating conditions applying to neutral grounding devices which are called upon only under line fault conditions to function under load, when fairly high temperatures may be reached for time periods ranging from one to ten minutes or more. By integrating the temperature-time area and using the eight-degree rule, temperature limits were approximated which were conservatively safe.

Where the aging of the insulation changes at a constant rate, that is, where it doubles for each 8, 10, or 12 degree increase in temperature, the temperature-time area can be integrated to obtain the amount of aging per cycle by the following equation:

$$A = t\left[\frac{\epsilon^{XT_2} - \epsilon^{XT_1}}{X(T_2 - T_1)}\right] \qquad (1)$$

where

A may be designated as aging units.

t = time, per cycle
ϵ = 2.718
T_2 = maximum temperature
T_1 = initial temperature
X = constant
- = 0.088 when aging doubles for each 8-degree increase
- = 0.0695 when aging doubles for each 10-degree increase
- = 0.059 when aging doubles for each 12-degree increase

It is usually more convenient to use a formula that gives the per cent of life used up per cycle of operation. This can be done by dividing the aging per cycle equation 1 by an assumed life at a given constant temperature.

For estimating the life of insulation as determined by tensile strength, I have used the following formula:

$$Y = 7.15 \times 10^4 \epsilon^{-0.088T} \qquad (2)$$

where

Y = life in years
T = temperature in degrees centigrade

It is well to point out that the laboratory tests reported in my 1930 paper (reference 7) indicate that the constant in equation 2 should be 4×10^4 which would give a life of four years at 105 degrees centigrade. My experience, however, has been that we should depend mostly on laboratory tests on small samples of insulations to give us the relative "rates of aging" at different temperatures, but that the life of transformers can best be determined by life tests made on actual transformers. Both laboratory aging tests on transformers and field experience have shown that the actual life of transformers operating at approximately 105 degrees hot test spot is more nearly like seven years than four years.

According to equation 2 the life of insulation is gone at the end of approximately seven years operation at 105 degrees centigrade. This is in fair agreement with the figure 21 which shows that the insulation has from 20 to 30 per cent of its strength left after operating from four to five years at 105 degrees centigrade. It is at the higher temperatures that the agreement is not so good because the curves in figure 21 show that the temperature must be increased more than eight degrees to double the rate of aging.

While the eight-degree rule may not be rigidly correct, particularly for high temperatures, I prefer to use it since it is more conservative than the data shown in figure

21. Even when using the eight-degree rule, one will be surprised at the large number of times that insulation can be subjected to short-time overloads, without using up its life.

If the eight-degree rule is used, and if equation 1 is divided by the constant in equation 2, and the number of hours per year, the following equation results:

$$F = \frac{t(e^{0.088T_2} - e^{0.088T_1})}{7.15 \times 10^4 \times 24 \times 365 \times 0.088(T_2 - T_1)}$$

$$= \frac{t(e^{0.088T_2} - e^{0.088T_1})}{K(T_2 - T_1)} \qquad (3)$$

where

F = fractions of life used up per cycle
K = 55.1×10^4 for time t expressed in hours per cycle

If t is expressed in minutes per cycle $K = 330.6 \times 10^7$.

Charles F. Hill (Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa.): The method of taking data by visual observation, introduced by Smith and Scott, is of considerable interest in the study of insulation deterioration. These observational data are quite consistent, even more so than the actual physical measurements, but are arbitrary in that the various six or eight stages of deterioration are established by mere definition. It would seem necessary to have simultaneous physical measurements before much confidence could be placed in such inspection data, but it is my opinion that such observations are quite worth while.

There is a considerable discrepancy between the physical data and observational data by Smith and Scott as is shown in figure 25 of their paper in the interval of 400 to 800 days operation where the mechanical data dips sharply. I am wondering if this dip is not due to some accidental phenomenon in the test.

Comparing the general rate of deterioration between the data by Smith and Scott and my own data ("Temperature Limits Set by Oil and Cellulose Insulation," AIEE TRANSACTIONS, volume 58, 1939, pages 484–91), it would appear that the rate in oil with a rather inert gas present is slightly faster than that for the test in restricted air by Smith and Scott. This is a surprising result, although not so impossible as our inert gas was not 100 per cent oxygen free. Small amounts of oxidation products of the oil might have a serious influence on the varnished cellulose materials.

In the discussion of results, Smith and Scott have reached a conclusion which, I believe, merits further emphasis. During the past few years, it has become customary for insulation engineers to speak of insulation deterioration rates doubling for each ten-degree-centigrade temperature rise. This idea has arisen because of the fact that in chemical reactions, rates of reaction do tend to change by a constant factor for constant temperature intervals. This is under the assumption, however, of constant materials and constant conditions of concentration, etc. Smith and Scott point out that such a rule does not hold for their life tests. We have also reached the same conclusion. The reason for the failure of this chemical law to hold for insulation life tests lies chiefly in the fact that in life tests, the material being tested is not the same material after a few weeks or months. The result is a very different rate of deterioration after some months than would be expected if the material remained a constant factor. Smith and Scott point out the danger from short-time tests. I would like to emphasize this particularly in that extrapolating rates from short-time tests may be very misleading.

Herman Halperin (Commonwealth Edison Company, Chicago, Ill.): This paper is extremely interesting and adds considerably to our knowledge. A few points that strike me are as follows:

1. Results of the tests tend to scatter considerably, as has been found by practically all investigators making any sort of comprehensive study.

2. A relatively short life will prevail for class *A* insulation operated continuously at the present "hot spot" temperature limit of 105 degrees centigrade of the AIEE rules. In my paper at this convention on "Load Ratings of Cable" (see 1939 annual TRANSACTIONS index for page numbers) I have indicated that for continuous operation it seems best from the standpoint of obtaining long life to have maximum temperatures not exceeding 85 or 95 degrees centigrade depending on how "continuous" the operation is at the higher temperatures.

3. If class *A* insulation is operated in normal service as is usually done, that is, at temperatures considerably below 105 degrees centigrade, then it becomes feasible to operate during emergencies at temperatures in excess of 105 degrees centigrade, presuming that such emergencies are infrequent and the temperature of the insulation is at the highest values for only a few hours during each emergency.

4. The operation during emergencies appears to do little more harm if the maximum temperature is around 140 than if it is around 120 degrees centigrade according to figures 22 and 23. In view of these unusual findings, it appears that the conclusions in my paper about operating low-voltage cables during emergencies at temperatures up to 120 degrees centigrade may be conservative.

In a series of six-month tests made at 100 and 125 degrees centigrade in Chicago on varnished cambric insulated cables, it was found that the rating of the quality of the various insulations as determined by mechanical and electrical tests on insulation removed from sealed cables was different from the rating found on the same insulations when tested in tape form in air. When heated as tapes exposed to air, the materials first hardened and improved in tensile and electrical strength but became more brittle. Some materials which appeared to be superior in such tests were found to become stuck together when heated in cable where air is excluded so that the cable could no longer withstand much bending without breaking the insulation.

J. J. Smith and J. A. Scott: We have endeavored to point out in the paper and it is again emphasized by Mr. Rylander that there are other factors in addition to the effect of temperature to be taken into consideration in determining the safe operating temperature of a machine. However, it is desirable to study these effects one at a time and therefore the present work was limited to the effect of temperature alone on the aging of insulation. We note Mr. Rylander's simple form of equations for life and it would be interesting if he added the value of K for some typical applications.

Mr. Alger points to the introduction of many new materials in recent years. The introduction of Formex wire is an example of such a development. As more of these materials become available, testing will be required to evaluate their performance compared with the older materials and the paper suggests a technique which may be used for this purpose.

Mr. Alger and Mr. Hill discuss the bearing of chemical changes on the aging problem and refer to a law the chemist often finds that the rate of change doubles for each 10-degree-centigrade increase in temperature. Such a law frequently holds for a single definite chemical reaction, and we would have been pleased if it had turned out that way in the present tests, but it did not. As pointed out in the paper, the consideration of the aging reactions from a physical and chemical standpoint as well as the effect of the structure itself is a subject worthy of more detailed study.

Mr. Montsinger's eight-degree rule is quite widely accepted in transformer practice and from all the evidence is conservative, as he points out when used to estimate the effect of increases in temperature. However, when the effect of decreases in temperature is considered as, for example, in estimating the service life of materials from short-time laboratory tests at elevated temperatures, the eight-degree rule may indicate a much longer life than is actually shown by these tests. In other words, the available evidence indicates that the actual rate of aging is not a simple law, but is dependent on many individual circumstances, so that the only safe basis for conclusions is actual operating experience.

Doctor Hill asks if some accidental phenomenon might account for the difference in the shape of the curves of physical and observational data in figure 25 between 400 and 800 days. These results were checked back to the original data and confirmed.

Doctor Hill points out that the aging rate he found in oil with inert atmospheres was faster than the rate in air given in our tests. Montsinger in his 1930 AIEE paper "Loading Transformers by Temperature" reports a similar behavior. This question of inert atmospheres is a fruitful field for future work, with the extended use of hydrogen cooling and other enclosed types of motors.

We are interested in Mr. Halperin's conclusion from work in connection with cable that the life of insulation operated continuously at the present "hot spot" temperature limit of 105 degrees centigrade is relatively short and his indication of a continuous temperature not in excess of 85 to 95 degrees centigrade. With regard to his discussion of higher operating temperatures in item 4 it should be remembered that the structure used in our tests is not the same as that in which he is interested and thus the results may not be directly applicable. His description of the results of aging tests on cable insulation both when sealed and aged in air indicate the necessity for care in comparing the results of aging tests made under different conditions.

Rating of General-Purpose Induction Motors

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Synopsis: This paper reviews principles of rating of general-purpose a-c motors, particularly in relation to overload torque and temperature limits.

The overload capacity of an electric motor is limited, first, by its stalling, or breakdown torque, and, second, by its operating temperature. The breakdown torque, analogous to the stalling torque of a gas engine, is roughly proportional to the motor size and the square of its magnetic flux density. The temperature limitation is exactly analogous to the temperature limit of a transformer, the useful life of the insulation being reduced exponentially as the temperature is raised.

The increased variety of motor uses in recent years, especially for automatic operation of refrigerator compressors, air conditioning, pumps, and other mechanical devices, has led to more exact methods of application, utilizing motor overload capacity and matching torque characteristics to the driven equipment. Under this economic pressure, motor overload capacities have been increased over the requirements of present standards, and small motors are now commonly used on intermittent overloads far beyond their continuous ratings.

It is proposed, therefore, that American standards be revised to provide for increased values of breakdown torque and service factor in the smaller motor ratings, and that permissible intermittent duty cycles be defined, enabling the full economic life of the motor to be utilized. It is also proposed that the starting current be recognized as a convenient and accurate measure of induction-motor breakdown torque, or momentary torque capacity, and that starting current values be established on a logical and consistent basis for both single-phase and polyphase motors.

Specific recommendations are given in the paper for rated characteristics and operating limits under this starting current-temperature system of rating, and the economic advantages to the industry to be gained by their adoption are pointed out, including safer wiring and control systems and a reduced variety of special motors.

THE importance of an adequate system of rating for industrial motors can hardly be overemphasized. The rated horsepower of a motor is a measure of its working ability, for whose integrity the entire electrical industry is responsible. The name-plate rating implies a host of different qualities built into the motor, including overload and starting ability, temperature endurance, high potential strength, and other matters covered by national standards. For the economic use of motors, the fair comparison of competitive designs, the maintenance of a proper and not excessive variety of types, the intelligent handling of power supply and control problems, and for many other reasons, it is essential that American standards of rating convey a definite guarantee of balanced characteristics and quality in motor design.

The essence of the rating problem is to find a simple test procedure that will uniquely define the output limitations of the apparatus in question. The outputs of gas engines, steam locomotives, pumps, turbines, and other mechanical apparatus are limited by mechanical considerations. Their continuous output ratings are, therefore, very little below their maximum momentary capacities, and users do not expect to load them appreciably beyond their ratings, even momentarily. On the other hand, the output of a transformer is limited almost entirely by thermal considerations, the theoretical point of maximum output with a constant voltage supply being far beyond the safe thermal limit. Hence, transformer users may permit high short-time overloads, so long as prescribed temperature limits are not exceeded.

Electric motors are subject to mechanical as well as thermal output limitations, both of which must be recognized in a practical rating system. The thermal limits are controlling in continuous operation, with present insulating materials, so that the close similarity between motor and transformer methods of rating that has always existed is entirely logical. In many cases, however, such as hermetic refrigerator motors, responsibility for cooling is entirely in the user's hands, so that usual temperature-rise guarantees will not be made by the motor manufacturer. Future trends will, therefore, assuredly require a rating system based on torque ability alone. The object of the present paper is to propose a transitional rating system, in which the temperature limits will be supplemented by other size-defining requirements.

Paper number 39-2, recommended by the AIEE committee on electrical machinery, and presented at the AIEE winter convention, New York, N. Y., January 23-27, 1939. Manuscript submitted October 20, 1938; made available for preprinting November 23, 1938.

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History

A thorough discussion of the motor rating question before the Institute and by the entire industry some 12 to 18 years ago resulted in the adoption of the present American system of a single continuous rating with 40 degrees centigrade rise for general-purpose motors. The conclusions at that period were ably summed up by C. L. Collens in a paper published in the August 14, 1926, issue of *Electrical World*, from which the following statements are quoted:

1. Any basis of rating is at best merely an arbitrary designation of size. It is merely one of many that might be chosen.

2. Rating alone is insufficient and must always be supplemented by a clear definition of the service conditions for which the rating is chosen. In fact, determination of the usual service conditions must necessarily precede the determination of a suitable basis of rating.

3. Rating alone is an insufficient indication of the inherent ability of the motor to perform satisfactorily under service conditions and duty cycles differing from the usual. It is merely one indication of size and must be supplemented by other service information to permit of intelligent selection and economic application.

In concluding his paper, Mr. Collens made the following recommendations:

1. The division of industrial power motors into two classes with the dividing line at 200 horsepower, and in each class:

2. A normal continuous-duty single rating for the open-type motor as the standard designation of size.

3. Well-defined usual service conditions for the normal rating.

4. Service information showing permissible loadings under other duty cycles or other service conditions different from the usual service conditions.

5. Specialized motors with special ratings only where the performance characteristics required or the nature of the duty cycle do not permit of applying a service factor to the normal rating of the standard motor.

Four of these five recommendations were carried into effect in the AIEE and National Electrical Manufacturers Association standards more than ten years ago, and experience since has well justified this action. Mr. Collens' fourth suggestion, however, that information should be prepared, showing permissible loading of standard motors under other duty cycles or unusual service conditions, has never

been adequately carried out nor incorporated in the industry standards.

The progress of the art during the past ten years, including the development of the modern automatically controlled cyclic loads of air conditioning and refrigeration, has brought a tremendous increase in number and variety of motor applications. The recent trend has been to develop many special motors, each adapted to drive a particular piece of mechanical equipment, often with overload and starting abilities much in excess of those normally associated with their name-plate continuous ratings.

The objectives of revised standards should be to specify a standard type of motor adapted for the greatest variety of applications and to facilitate the economic use of the full capacity of the motor under all service conditions.

The Present Rating System

Present American standards[1] provide for two broad classes of continuous-rated motors.

General-purpose motors (200 horsepower or less and 450 rpm or more) have a single continuous rating, but must be suitable for carrying 115 per cent of rated load continuously under usual service conditions, with the ambient temperature 40 degrees centigrade or lower. These motors are offered in standard ratings for use without restriction to a particular application. They are required to meet the low limiting temperature rise of 40 degrees centigrade by thermometer at rated load, to allow a greater factor of safety where the service conditions are unknown.

Special-purpose motors, specifically designed for a particular power application where the load requirements and duty cycles are definitely known, have a single continuous rating of 50 degrees centigrade rise by thermometer, without any continuous overload requirements.

The standards also specify minimum values of starting, pull-up, and breakdown torques for each type and class of motor.

These provisions should undoubtedly be retained, but it appears desirable to add to or modify them in four respects:

First, the standards should include operating recommendations for general-purpose motors in intermittent or varying load service and in different ambient temperatures, so that the inherent overload capacity of the motor can be safely utilized. This is in accordance with the action already taken in the recently proposed American standards for transformers.

Second, the general use of small motors in intermittent rather than continuous service should be recognized in the standards by requiring relatively greater starting and breakdown torques, and greater temporary overload capacities, than for larger motors. Unless such provisions are made, off-standard motors will be used to an increasing extent, and control problems will be complicated, to the detriment of the public as a whole.

Third, the more general use of various protected motor designs suggests that their allowed temperature rises be reviewed and their ratings be made more nearly comparable with general-purpose motors.

Fourth, the more complete utilization of motor overload capacities, implied by this program, should be accompanied by more exact determination of insulation temperatures. In many modern designs, especially of protected* motors, the windings are quite inaccessible, and thermometer readings on exposed parts do not accurately measure hot-spot temperatures. It appears desirable, therefore, for the standards to require that stator-winding temperatures be measured by resistance. This fourth question is the subject of a companion paper.[2]

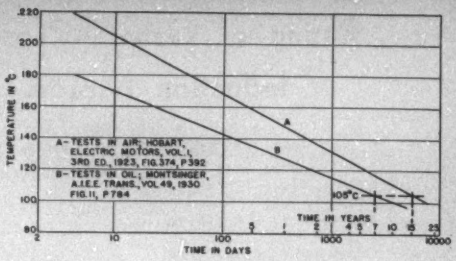


Figure 1. Life expectancy versus temperature for class A insulating materials in continuous service

Overload Capacity of Standard General-Purpose Motors

Assuming adequate mechanical strength, the measure of a motor's momentary overload capacity is the adequacy of its torques, giving assurance that the motor can bring the load to speed and carry it under low voltage, high friction, or other unforeseen temporary conditions. American standards now require that general-purpose polyphase induction motors shall have a breakdown torque of not less than 200 per cent. Allowing for ten per cent reduction in voltage and 20 per cent margin for variations in individual conditions of loading, this 200 per cent breakdown torque will enable loads not over 135 per cent of the rating to be carried successfully, subject to heating limitations.

Therefore, under the present standards, motors cannot be relied upon to carry momentary overloads of more than 35 per cent in excess of the rating, under a reasonable variety of service conditions. In practice, designers normally provide more breakdown torque than required by the standards, especially for the smaller and higher-speed motors, so that many present designs can carry considerably greater short-time overloads.

It should be remembered that the starting current of a large polyphase induction motor is almost directly proportional to the maximum or breakdown torque. The starting current is, therefore, an excellent measure of short-time overload ability.

With adequate torque margins, the remaining important factor in overload capacity is the temperature rise. This must be low enough to ensure adequate service life under the expected overloads. While there may be other objections to high temperatures in special cases, the chief purpose of limiting the standard temperature rise is to protect the public from the inconvenience and loss that would be occasioned by motors with a short insulation life. As the actual life that a motor will have under a given temperature cannot be determined by acceptance tests alone, it is peculiarly important that the standards provide for safety in this respect.

When and if insulating materials of greater temperature endurance come into use, they may be utilized to permit reduction in motor size, with a higher continuous rise. It seems desirable, however, to use such higher temperature materials and limits first on totally enclosed machines, permitting interchangeable dimensions with open-type motors of present temperature limits. For open-type

1. For all numbered references, see list at end of paper.

* Protected is used here to describe partially or fully enclosed motors as a class.

motors with liberal overload torques, and reasonable efficiencies, it costs very little to provide ventilation adequate to meet present temperature limits. The only apparent gain from higher temperature limits on open-type general-purpose motors, therefore, is a small saving in the cost and losses expended in the ventilating system. For enclosed machines, however, a definite size reduction with increased temperature can usually be made without impairing operating characteristics, and this benefit may justify developing new higher-temperature insulation systems.

It is evident that the increase of copper resistance with temperature causes a decrease in efficiency with every increase in the operating temperature. In a typical case of a motor with 90 per cent full-load efficiency at 75 degrees centigrade, the efficiency will be reduced 0.5 per cent by an increase to 105 degrees centigrade copper temperature, or by 1.25 per cent if the temperature is raised to 150 degrees centigrade. Such an increase in the losses further raises the temperature, causing cumulative heating, or "temperature creep," as indicated in figure 4. This forms an effective limitation on high normal temperature rise, or continuous overloads. Rapid oxidation of oil and consequent need for separately cooled bearings and frequent oil renewal at temperatures above 100 degrees centigrade are additional reasons for limiting temperatures in continuous service.

Temperature-Life Characteristics of Insulation

In this paper, we shall assume that the allowable temperature of the motor should be so specified that a motor in continuous service at rated load and maximum ambient temperature will have adequate life, with present insulating materials. Available information on temperature life of cellulose insulation was summarized by V. M. Montsinger[3] some years ago, in connection with studies of transformer insulation under oil, that have since formed the basis for the recently published American standards for transformers.

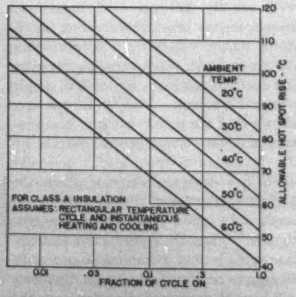


Figure 2. Permissible increase in hot-spot temperature rise to secure same life expectancy in intermittent service as in continuous service at 102 degrees centigrade

Although these test data indicate a materially longer life of cellulose materials in air than under oil, some information from longer test periods[4] that is available suggests that over long periods of time the life in air and oil will not be materially different. For the present paper, therefore, the same temperature life curve as generally used for transformers will be employed, as shown in figure 1*B*. This indicates that the life of class *A* insulation will be halved for each 8 degrees centigrade increase of temperature. The curve gives a materially shorter life than the *A* curve, which represents the best information available in 1925, when the present AIEE standards of temperature limits were established. If steadily maintained at a temperature of 105 degrees centigrade, the curves indicate the insulation will theoretically reach the end of its useful life in seven years, or will then be subject to immediate failure under any mechanical or electrical shock.

General-purpose motors with a 40 degrees centigrade ambient and a 40 degrees centigrade rise at full load by thermometer will normally have an actual hot-spot temperature of not over 102 degrees centigrade, when operated continuously at 115 per cent of the rating, in accordance with the standard service factor; indicating about ten years' useful life. Since, in practice, the average ambient temperature in the United States is generally below 30 degrees centigrade, the typical motor operating continuously at 115 per cent of its rating will have an average hot-spot temperature of about 90 degrees centigrade, giving an indicated useful life of roughly 25 years. When motors are operated below their ratings, considerably longer insulation life may be expected. This accords well with experience and indicates that our present standard basis of rating is satisfactory, for fully continuous service in normal ambients.

If, however, a motor is employed on intermittent service, with short-time overload periods repeated at intervals of hours, days, or longer, and periods of complete idleness between, the actual life of the motor at the same loading may be considerably longer, temperature alone considered. Therefore, reasonably higher temperatures may be permitted on intermittent service.

We shall assume that whether a motor is operated at a given high temperature one month in every ten, or on any other cycle with the motor idle nine-tenths of the time, the insulation will deteriorate at the same average rate, giving the same total years of life. We shall assume also that the temperature life curve is a constant exponential curve as indicated by figure 1, and that temperature variations are not accompanied by other deteriorating conditions, such as variable dirt or moisture exposure. In practice, these conditions are not strictly true, but over the moderate range of temperature variation considered, the assumptions appear justified.

Consideration of figure 1 readily enables the actual temperature to be determined that will give the same life in years on any intermittent service. Figure 2 shows, for example, that, if the motor is idle nine-tenths of the time, it may be permitted to have a hot-spot temperature rise 26.5 degrees centigrade greater than normal, and still have the same life in years as the standard motor operated continuously at 115 per cent of rating. To find the permissible overload on the motor, corresponding to this additional temperature rise, reference must be made to the characteristics of a typical general-purpose motor.

Normal Induction-Motor Characteristics

If a motor is designed solely for continuous operation at rated load, it will normally have its maximum efficiency point near 75 per cent load, giving the most favorable over-all performance. If the maximum efficiency point always occurs at the same fraction of full load, the no-load losses will bear about the same proportion to the full-load losses for all motors in the line. Keeping the same percentage of breakdown torque for all sizes of motor, in accordance with the present standards, and keeping the same balance of losses as indicated, the performance curves and equivalent circuit of the typical general-purpose induction motor can immediately be determined. The chief differences between motors of different speeds and horsepower will be that the percentages of no-load current, full-load power factor, and total losses will vary. Figure 3 shows the performance curves and the equivalent circuit for such a typical polyphase motor, which closely represents an average 4-pole 25-

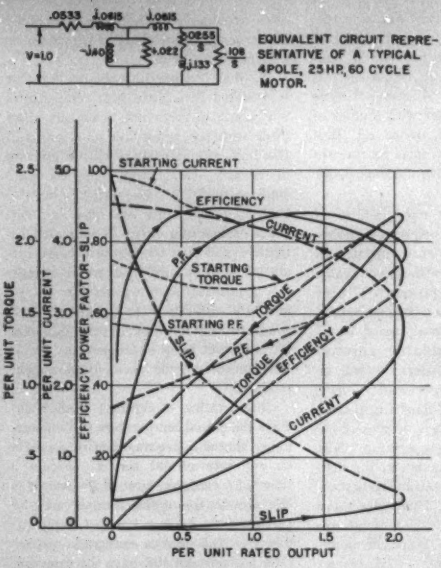


Figure 3. Operating characteristics of a typical four-pole general-purpose polyphase motor

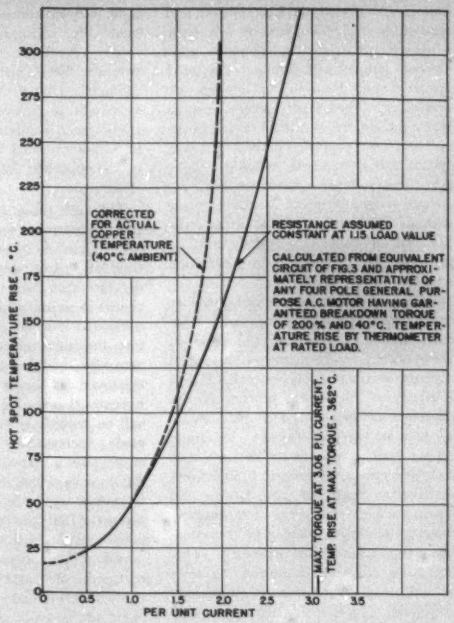

CORRECTED FOR ACTUAL COPPER TEMPERATURE (40°C. AMBIENT)
RESISTANCE ASSUMED CONSTANT AT 1.15 LOAD VALUE
CALCULATED FROM EQUIVALENT CIRCUIT OF FIG. 3 AND APPROXIMATELY REPRESENTATIVE OF ANY FOUR POLE GENERAL PURPOSE A.C. MOTOR HAVING GUARANTEED BREAKDOWN TORQUE OF 200% AND 40°C. TEMPERATURE RISE BY THERMOMETER AT RATED LOAD.
MAX. TORQUE AT 3.06 P.U. CURRENT. TEMP. RISE AT MAX. TORQUE = 36.2°C.
HOT SPOT TEMPERATURE RISE - °C.
PER UNIT CURRENT

Figure 4. Hot-spot temperature rise versus current for typical four-pole general-purpose motor

horsepower 220-volt design. The circuit was chosen to give a maximum torque at normal voltage of 220 per cent (10 per cent greater than the 200 per cent value required by the standards), providing the usual margin necessary to be sure of meeting guarantees.

Many polyphase induction motors now have double squirrel-cage or deep-bar rotors, to get increased starting torque without impairing efficiency in normal operation, and the circuit constants shown in figure 3 are representative of this type. Light and heavy broken-line curves indicate the starting characteristics of the double and single squirrel-cage designs, respectively. The curves indicate that a starting (locked rotor) current of at least 500 per cent of full load must be allowed, if 200 per cent breakdown torque is required. The actual value of starting current will vary for different sizes and speeds of motor, depending on their efficiency, power factor, and starting torque values, but a figure of 14 amperes per rated horsepower for 220-volt 3-phase 60-cycle motors larger than 15 horsepower represents the lowest that can be expected. Any increase in breakdown torque will require a proportional increase in starting current, 250 per cent breakdown torque requiring 17.5 and 300 per cent requiring 21 amperes per rated horsepower on the same basis. The smaller motors also will have greater starting currents for a given breakdown torque than large motors, due to their lower power factors and torque efficiencies, and higher starting-torque requirements.

Many temperature tests on different motors indicate that for low-voltage designs the temperature rise of the winding is closely proportional to the total losses in the motor, regardless of where they occur.[1] For overload conditions especially, the hot-spot temperature rise may be taken as directly proportional to the total losses without important error.

If, therefore, we assume that all motors are provided with ventilation just adequate to hold the temperature down to the rated value of 40 degrees centigrade rise by thermometer at full load, a single temperature-rise-versus-current curve may be drawn, that will be closely representative of a wide range of motor sizes and speeds. Such a curve is shown in figure 4, the temperature rise being in direct proportion to the losses given by the equivalent circuit of figure 3. Degrees are plotted against percentage of full-load current, rather than against horsepower or torque, to allow for the variations in the no-load current and no-load temperature rise for motors of different sizes and speeds. The dotted curve indicates the additional temperature rise due to increase of copper resistance with temperature,* showing the cumulative heating effect of prolonged overloads.

Although figure 4 is drawn for a motor with exactly 220 per cent breakdown torque, it may be applied to other breakdown torque values by a proportionate change in scale. The curve shown gives hot-spot temperatures, rather than simply observable values. Many heat runs have shown that the actual hot-spot temperature in a low-voltage general-purpose induction motor at rated load is generally about five degrees centigrade above the highest thermometer rise, and rarely exceeds it by more than ten degrees centigrade. Thus, the conservative assumption is made that a standard motor with 40 degrees centigrade rise by thermometer will have 50 degrees centigrade rise at the hottest spot on the insulation.

* Neglecting the increase in watts dissipated per degree of rise at elevated temperatures.

At the service factor rating of 115 per cent load, the motor losses are 123 per cent of full-load losses (figure 3), making the temperature rise 49 degrees by thermometer or 62 degrees at the hottest spot. Thus, the service factor rating corresponds very closely to the 50 degrees centigrade rise permitted by the standards for special-purpose motors, of which the load conditions are definitely known in advance. The 13 degrees centigrade rise at the hot spot above the test value of temperature rise assumed for this typical low-voltage induction motor is a little less than the 15-degree allowance in the standards.

Permissible Intermittent Overloads

Comparison of figures 2 and 4 enables us to determine the permissible overload current on a standard motor for any degree of intermittency of loading. The full-line curves of overload current versus fractional operating time for different ambient temperatures, shown in figure 5, all correspond to the same ten-year life expectancy. The lower of the two 40-degree-centigrade ambient curves indicates the effect of temperature creep, corresponding to the dotted curve of figure 4.

Inspection of this figure shows that short-time overloads well in excess of 135 per cent of rated current are permissible in usual 20 degrees centigrade to 30 degrees centigrade ambients, without exceeding economic heating limits. As previously indicated, however, this 135 per cent value is roughly the highest load the present standard motor can carry without risk of breakdown under ten per cent low voltage and other varying conditions of service. Hence, to utilize fully the economic life of motors in intermittent service, higher breakdown torques than 200 per cent are required.

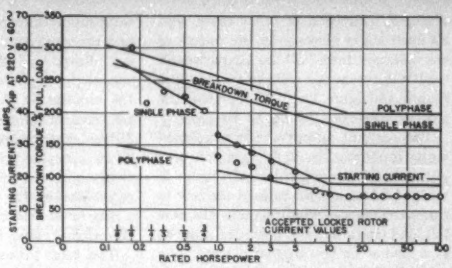


Figure 6. Recommended breakdown torques and starting currents (locked rotor) for four-pole general-purpose a-c motors of different horsepower ratings

It should be noted that figure 5 is derived on the basis of no lag of temperature behind the applied load, or instantaneous heating and cooling. For duty cycles involving many hours of continuous running interspersed with long idle periods, this is satisfactory, but for running periods of two hours or less, it gives very conservative values. At the limit, with very short cycles, the average loss can be assumed constant over the entire period, and the aging will correspond to the temperature rise due to $1/n$th of the operating plus starting losses, if the idle time is $(n - 1)$ times the operating time.

Knowing the heating and cooling curves, or thermal time constants, of any motor, it is readily possible to determine the temperature-time curve, and hence the aging effect, of any duty cycle. In appendix II of this paper, such calculations have been carried out, and the curves of figure 11 have been derived, enabling the permissible temperature rise above normal to be determined, and hence, from figure 3, the permissible overload current to be found, for any actual cycle, and for motors of different sizes.

Everything considered, therefore, it seems proper to use the ideal zero time constant curves of figures 2 and 5 for operating recommendations, recognizing that the extra heating due to acceleration losses in starting, and temperature creep, on higher overloads, offset a large part of, but not all of, the beneficial effects of time lag in temperature rise on short cycles.

Characteristics of Motors Designed for Intermittent Service

If a continuous-rated motor is applied on an intermittent load, therefore, and the insulation is to be used to the full extent of its economic life, the motor can evidently be operated at an output greater than the continuous rating, and it should be designed with a higher breakdown and starting torque ability than required for continuous service. Knowing the fractional operating time and the desired motor life, the permissible temperature rise is found from figure 2. For greatest economy, the motor should then be designed to obtain the maximum possible horsepower output at this temperature rise. The designer does this by first varying the number of turns in the motor winding, and finding for each case the current loading with the given supply voltage that gives a total power loss corresponding to the permitted temperature rise. The maximum power output for these conditions is obtained when the maximum point on the efficiency characteristic coincides with the loading that gives the permitted total losses.

In practice, the maximum efficiency point should occur a little below the operating point to secure better light-load efficiency and power factor and lower starting current. We shall assume, therefore, that the winding turns will finally be chosen to make the maximum permissible load for the desired intermittency always occur at the 115 per cent load point on the standard-motor characteristic curves, giving the same torque characteristics as in continuous operation at the original 115 per cent service-factor rating.

If the equivalent circuit constants of the motor do not change from increased

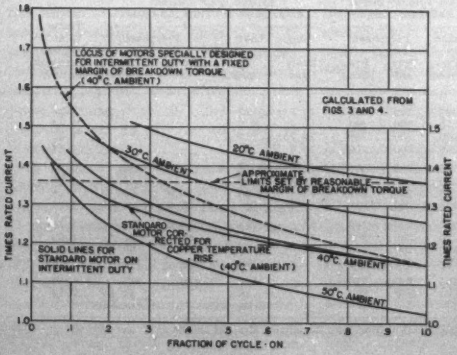

LOCUS OF MOTORS SPECIALLY DESIGNED FOR INTERMITTENT DUTY WITH A FIXED MARGIN OF BREAKDOWN TORQUE. (40°C. AMBIENT)
CALCULATED FROM FIGS. 3 AND 4.
20°C. AMBIENT
30°C. AMBIENT
APPROXIMATE LIMITS SET BY REASONABLE MARGIN OF BREAKDOWN TORQUE
STANDARD MOTOR CORRECTED FOR COPPER TEMPERATURE RISE (40°C. AMBIENT)
SOLID LINES FOR STANDARD MOTOR ON INTERMITTENT DUTY
40°C. AMBIENT
50°C. AMBIENT
TIMES RATED CURRENT
TIMES RATED CURRENT
FRACTION OF CYCLE - ON

Figure 5. Permissible current loading of four-pole general-purpose motors in intermittent service, for the same insulation life expectancy

magnetic saturation or other cause, and all fixed losses increase as the square of the volts per turn,* all the characteristic curves of the motor will retain the same shapes, and figure 3 will still represent the motors redesigned for higher torques.

The per unit output of the redesigned motor is obtained by multiplying the output scale for the original motor, figure 3, by $1/a^2$, where a is the ratio of the new to the old number of winding turns, the new full load characteristics being the same as at a load a^2 on the original motor. The rated load in horsepower is assumed to remain the same in all cases.

By this process, the efficiency and, therefore, the total losses and temperature rise at rated load will be slightly changed from their original values. A limit is set on this stepping up of the torque with reduced winding turns by the excessive increase of no-load current when the magnetic flux density is increased beyond the saturation point. For low-speed motors particularly, there is a definite value of volts per turn of winding beyond which a further increase will reduce instead of increasing the breakdown torque, for fixed magnetic dimensions. A further limitation is set by the rapid increase in full-load current and temperature as the maximum efficiency point is brought beyond the point of rated load.

For example, taking 40 degrees centigrade ambient temperature and an ideal load cycle with only 0.06 of the time operating, the rest idle, the permissible motor temperature rise at the hottest spot is 94 degrees centigrade, as compared to 62 degrees centigrade for the standard motor operating at 1.15 times rated load, from figure 2. Hence, the allowable total losses can be increased to 1.52 times, and the volts per turn should be raised by a factor of 1.23. At this increased magnetic density (neglecting saturation), the motor will have an output at 94 degrees centigrade hot-spot temperature rise of 1.52×1.15 or 1.75 times the original horsepower rating, and the breakdown torque will be 1.52 times larger, or will still be 174 per cent of the output (190 per cent including the 10 per cent margin of the average motor of figure 3), the same as for the original motor operating at the 115 per cent service-factor rating.

Figure 7 compares the calculated temperature rise-current curves for the motor of figure 3 before and after rewinding with 1/1.23, or 0.81 as many turns, with the same supply voltage, the same ventilation, and the same continuous horsepower rating. Rated load efficiency and power factor on the new characteristic curves are the same as at $(0.81)^2$, or 0.66 load for the original winding, or 89.3 per cent and 79 per cent, respectively, from figure 3. These compare with 88.9 per cent efficiency and 86.5 per cent power factor for rated load on the original motor, giving a new rated load current 108 per cent of the original value, in amperes.

The total losses at rated load being 10.7 per cent instead of 11.1 per cent of input, the temperature rise at rated load will be 38.5 degrees centigrade by thermometer, or 48 degrees centigrade at the hot spot, a little lower than before. The efficiency at 115 per cent load on the rewound motor is 89.8 per cent as compared to 88.2 per cent originally, so the temperature at this load is $1.15 \times 10.2/-10.7 \times 89.3/89.8 \times 48 = 52.5$ instead of 62 degrees centigrade. From figure 7, 62 degrees centigrade rise is reached at 122 per cent current on the new motor, which, from figure 3, corresponds to 132 per cent load. Hence, the redesigned motor has a service factor of 1.32 in place of 1.15. If, however, the 40 degrees centigrade rise at rated load had been adhered to, 62 degrees centigrade rise would be reached at 119 per cent current, corresponding to 125 per cent load.

The overload current-temperature curves of figures 5 and 7 apply fairly closely to a wide range of motor sizes, but differences in power factor and efficiency curves will cause considerable differences in the corresponding output curves for different sizes. In general, the lower full-load power factor and higher no-load losses of the smaller motors will cause their overload currents to increase less rapidly than their outputs, so giving them higher service-factor ratings than large motors.

Recommended Characteristics

Since small motors are usually applied on intermittent loads, it is obviously desirable to design them for a moderate degree of intermittency rather than for continuous service. Experience has shown that motors with minimum breakdown torque values varying from 200 per cent for 15 horsepower and larger, up to 300 per cent for 1/8 horsepower, are well suited for average starting and load requirements, and it is proposed that these values be adopted as standard for polyphase motors, in place of the flat value of 200 per cent now standard. On small motors with high starting torque, which have more than 20 per cent slip at maximum torque, the torque at 80 per cent speed is taken as the breakdown value. This 80 per cent speed point is chosen as the measure of breakdown torque in recognition of the fact that higher torques which may be available at lower speeds are only useful in starting, rather than in overload operation. Integral-horsepower normal-torque motors usually have less than 20 per cent slip at breakdown. Figure 6 shows the proposed variation of torque with horsepower rating.

In comparing single and polyphase motors for the same service, it is found that the single-phase motor (of either repulsion or capacitor type) has normally greater starting torque, greater service factor, and lower slip for the same value

Table I. Characteristics of Proposed Standard General-Purpose A-C Motors With 40 Degrees Centigrade Rise by Thermometer at Rated Load

Horsepower	Breakdown Torque* in Per Cent of Full-Load Torque				Locked Rotor Current Amperes at 220 Volts, 60 Cycles				Service Factor in 40 Degrees Centigrade Ambient
	Single Phase		Polyphase		Single Phase		Polyphase		
	Present	Proposed	Present	Proposed	Present	Proposed	Present	Proposed	
1/8	175	275	200	300	10	7	3.75	1.50	
1/6	175	270	200	295	10	9	5	1.45	
1/4	175	260	200	285	10.75	12.5	7	1.40	
1/3	175	255	200	280	15.5	16	9	1.35	
1/2	175	245	200	270	22.5	22	13	1.30	
3/4	175	235	200	260	30.5	30.5	19	1.30	
1	175	230	200	255	33	33	26.6	22	1.25
1 1/2	175	225	200	250	45	45	36.6	31.5	1.25
2	175	215	200	240	55	57	46.6	40	1.20
3	175	210	200	235	75	77	60	57	1.20
5	175	200	200	225	110	110	89	90	1.15
7 1/2	175	190	200	215	145	120	120	1.15	
10	175	185	200	210	180	150	155	1.15	
15 and up	175	175	200	200	18× horsepower		14.5× horsepower	1.15	

* When the maximum torque occurs at more than 20 per cent slip, the torque at 80 per cent speed is taken as the breakdown value.

* Actually, the friction and windage will not increase, unless larger bearings are required for the higher torques, but the core and exciting current losses will increase somewhat faster than the volts per turn squared. The two effects will counteract each other so completely that their combined effect may be neglected for our purposes.

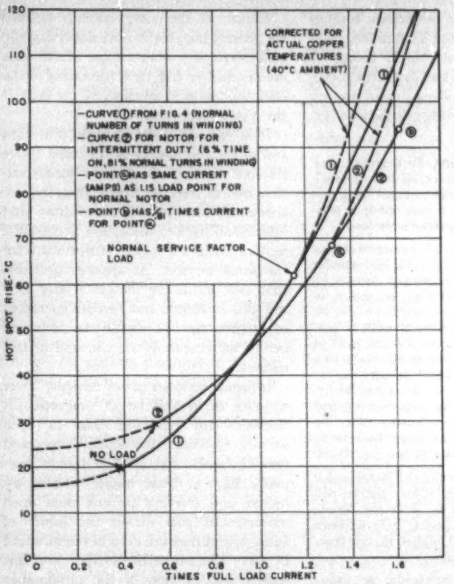

CORRECTED FOR ACTUAL COPPER TEMPERATURES (40°C AMBIENT)
— CURVE ① FROM FIG. 4 (NORMAL NUMBER OF TURNS IN WINDING)
— CURVE ② FOR MOTOR FOR INTERMITTENT DUTY (6% TIME ON, 81% NORMAL TURNS IN WINDING)
— POINT ⑤ HAS SAME CURRENT (AMPS) AS 1.15 LOAD POINT FOR NORMAL MOTOR
— POINT ⑥ HAS 1/.81 TIMES CURRENT FOR POINT ⑤
NORMAL SERVICE FACTOR LOAD
NO LOAD
HOT SPOT RISE-°C
TIMES FULL LOAD CURRENT

Figure 7. Hot-spot temperature rises of standard and intermittent-duty types of motors

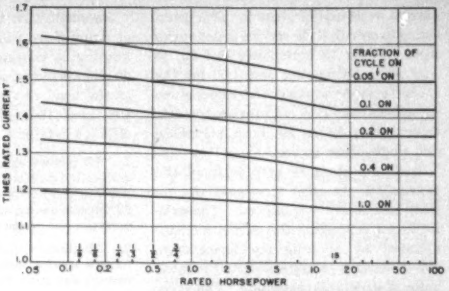


Figure 8. Permissible current loading, in intermittent service, with 40 degrees centigrade ambient, of four-pole general-purpose a-c motors, having breakdown torques in accordance with figure 6

of breakdown torque. A repulsion-start motor, for example, usually has a starting torque of over 400 per cent, and a pull-up torque considerably less than the breakdown value, while a small polyphase motor has a starting torque only a little greater than the 80 per cent speed value, and a pull-up torque fully equal to the breakdown value. Capacitor-start single-phase motors have intermediate characteristics. Experience has shown that the characteristics of the two types are best matched when the breakdown torque of the single-phase motor is equal to about 90 per cent of the polyphase value. Present standards, recognizing this, require only 175 per cent breakdown torque for single-phase motors. It is proposed, therefore, that single-phase-motor breakdown-torque values be standardized 25 points lower than for polyphase, varying from 275 per cent for $\frac{1}{8}$ horsepower to 175 per cent for 15 horsepower, figure 6.

In figure 6 also are shown proposed limiting starting-current (locked rotor) values for single and polyphase motors, chosen to enable the specified breakdown torque values to be obtained with reasonable margin. Circled points show present accepted, but inconsistent, values of starting current. The amperes per horsepower increase in the smaller sizes in approximately direct proportion to the increase of breakdown torque, and in inverse ratio to the apparent efficiency at rated load. The break in the current curves between fractional and integral horsepower ratings is due to the higher starting-torque requirements in the fractional sizes, to provide for relatively higher friction and greater variations in service conditions. The general use of repulsion motors, which inherently have a higher ratio of starting to pull-up torque, and lower starting currents, than capacitor-start motors, has made it customary to specify much higher starting torques for fractional-horsepower motors than required by the load in most cases. It may be, therefore, that future trends will reduce these starting torque requirements below the present levels of about 400 per cent of rated value, and in this case the fractional-horsepower starting-current levels could be reduced also.

The single-phase locked-rotor currents given are proposed to cover capacitor-start motors, and are appreciably higher than necessary for repulsion-start motors. The proportional relation between starting current and breakdown torque also does not hold as accurately for repulsion-start motors as for pure induction motors, due to possible changes in brush position on the repulsion types.

These starting-current values are especially important to control engineers, underwriters, and power-supply authorities, because they determine the necessary fusing, overload control, wiring, and voltage-regulation requirements. From every viewpoint of safety and convenience, it is desirable to have a definite, one-to-one correspondence between locked-rotor current and name-plate horsepower for a given supply voltage. If the values proposed in figure 6 are adhered to, they will permit economic motor use with uniform safety and control practice, and give reasonable assurance that a motor of the next lower or higher rating capacity is not masquerading under a false name plate.

The dotted line in figure 5 shows the permissible overload current capacities without reduction of breakdown-torque margin, obtained by using a different winding for each load cycle, with 81 per cent turns for 0.06 operating time, 84 per cent for 0.10 time, etc. By designing each size of the line of motors to have the breakdown-torque value indicated in figure 6, and using these modified motors for all duty cycles, reasonably increased overload capacity can be obtained with normal efficiency, at the expense of reduced full-load power factor and increased starting current, but with starting torque higher in proportion to the increased breakdown torque.

Figure 8 shows the permissible current overloads in intermittent service, for different sizes of motor, each designed to meet the breakdown torque requirements of figure 6, and to have 40 degrees centigrade rise by thermometer at rated load. Figure 9 shows typical current-output curves for these same motors. From these two sets of curves, figure 10 is derived, giving the permissible torque overloads, or power outputs, corresponding to the

current overloads of figure 8. It is interesting to note that the service factor varies from 1.15 for 15 horsepower and up, to 1.25 for 1 horsepower and 1.50 for the $^1/_3$-horsepower ratings. The values given have been rounded off to give a single conservative figure for both polyphase and single-phase motors.

It is important to keep in mind the reasons for the high service factors on fractional-horsepower motors. The service factor represents the output increase obtained by allowing the temperature rise to increase 10 degrees above the rated value of 40 degrees centigrade. This gives 1.15 to 1.19 times rated current over the range of $^1/_8$ to 100 horsepower 4- and 6-pole motors, figure 8. Fractional-horsepower motors, having inherently lower power factor and efficiency, and being called on to deliver higher starting and breakdown torques than large motors, inevitably have no-load current values only slightly lower than at full load. Hence, their current-output curves, figure 9, are much flatter than for large motors. Small motors have also inherently large mechanical factors of safety, as their shaft and bearing sizes are fixed by stiffness rather than torque requirements. Finally their large surface areas per unit of power loss, and their thin insulation give them relatively much better heat dissipating characteristics than large motors. Electrical, mechanical, and thermal characteristics all combine, therefore, to make lower service factors appropriate for large than for small motors.

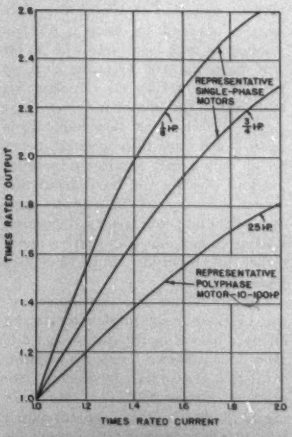


Figure 9. Typical current versus horsepower curves for four-pole general-purpose motors, having breakdown torques in accordance with figure 6

Assuming that the breakdown torques of figure 6 are adopted as standard, and keeping a continuous single rating of 40 degrees centigrade rise by thermometer at full load, the resulting line of motors will have the following characteristics, as listed in table I:

1. All motors will have 40 degrees centigrade rise by thermometer, 50 degrees centigrade or less hot-spot rise at rated load, and 62 degrees centigrade or less hot-spot temperature rise at the service-factor load.

2. All motors above 15 horsepower will have a service factor of 1.15, and smaller motors will have higher service factors up to 1.50 for $^1/_3$ horsepower, as shown in figure 10.

Thus, continuous operation could be permitted at 115 per cent to 150 per cent of rated load for the various motor sizes, in a 40 degrees centigrade ambient, with an expected insulation life of about ten years. Lower ambients usually experienced, and noncontinuous operation, will lengthen the normal insulation life at rated load to 25 years or more under usual service conditions.

3. The breakdown torque and locked-rotor current values for different horsepowers will be as shown in figure 6. Starting torque values will be proportional to breakdown torques, but relatively higher in the fractional-horsepower ratings.

4. The permissible overloads, or intermittent service factors, in percentages of rated current and rated torque are shown in figures 8 and 10 for several ratios of operating to elapsed time. Limits set by a breakdown torque margin of 150 per cent are indicated.

These values are based on the conservative assumption of zero time lag of temperature. More exact values, taking into account the actual heating and cooling time constants, can be determined by the methods outlined in appendix II.

Rating of Protected Motors

The general use of protected motors with different degrees of enclosure suggests that their permissible overloads should also be determined. Present standards allow 50 degrees centigrade rise by thermometer, for splashproof motors, and 55 degrees centigrade for totally enclosed and fan-cooled designs, with a service factor of 1 instead of 1.15. The extra 5 degrees centigrade for enclosed motors is generally understood to be allowed because of the smaller difference between the hot test spot and the measured temperature than in open motors. The standards imply, therefore, that all fully protected motors will have a hot-spot temperature rise at rated load of 65 degrees centigrade, or practically the same as that of the standard general-purpose motors of the open type at 115 per cent load.

Hence, all the curves already derived for general-purpose motors apply equally well to enclosed motors if the actual loads are divided by 1.15, or if the rating of the enclosed motor is taken as 87 per cent of the name-plate value.

It is very desirable to build protected and open-type motors in the same frame size and with interchangeable characteristics, and it may be urged that the exclusion of dirt, excessive moisture, and other protection to insulation in enclosed motors justifies a higher temperature for the same service. It appears probable that new insulating materials may permit this in future, but further operating experience records should be obtained before the standards are changed in this respect.

In usual enclosed motor designs, fewer winding turns and larger magnetic dimensions are employed than in open motors, to reduce the copper losses and temperatures. Hence, such motors normally have a little higher breakdown torque and starting current than open motors, but still within the limits of figure 6, and they are even better adapted to carry short-time overloads. For this reason, and in view of the presumably longer insulation life at a given temperature because of moisture and dust exclusion, it is suggested that service factors be applied to enclosed as well as open motors. While no specific recommendations are now offered, it is clear that the inherent ability of an enclosed motor to deliver short-time overloads will be utilized in the long run, and standards or operating recommendations should be prepared to facilitate this.

The cooling of motors for hermetically sealed refrigerators, enclosed gas pumps, and other built-in applications, is entirely in the control of the user. Temperature rating standards do not apply to such motors, therefore, and the operating temperature may be anything that the user's experience justifies. By adhering to the proposed breakdown-torque and starting-current rules, and normal efficiency values, however, assurance is given that the motor will have the torque ability represented by the name-plate horsepower. With improvements in insulating materials, such torque and starting-current rating methods may be expected to supersede the temperature system to an increasing extent.

Conclusions

The whole object of this discussion is to make the standard motor fit as many uses as possible. It should have a simple,

generally understood name plate that guarantees its satisfactory performance in continuous duty, and there should be supplementary information describing its proper application in all sorts of different duties.

The recommendations for breakdown torque and starting current values for standard general-purpose single-phase and polyphase induction motors given in table I, and the associated permissible overloads in intermittent service, figure 10, are believed to provide a logical and comprehensive system of rating. The information on permissible overloads is proposed in the form of operating recommendations, rather than as hard and fast requirements of standards. This system provides for motors designed to fit the maximum variety of applications, and it permits the user to apply them intelligently up to the limits of their economic life. It ties together the present differing practices on fractional- and integral-horsepower motors and permits merging the important requirements for automatically controlled refrigeration and air-conditioning motors with the standard general-purpose designs.

The plan does not disturb the basic principles of motor rating so well established some 15 years ago, but carries them forward along proved lines. It divorces the operating recommendations from the rating standards, and lays a foundation for the more flexible use of motors in new fields and their more ready adaptation to future developments.

The numerical values given in the paper have been presented as illustrative of the principles involved, rather than as final values for standards. Necessarily, the characteristics of motors made by different manufacturers will vary from those used for illustrations in the paper, and an industry-wide review of experience must be made before any action on standards can be taken. It is also desirable to extend the analysis to cover motors of other speeds besides the four-pole designs which have alone been considered in the paper. And, finally, the temperature-life curve of figure 1, forming the basis of the values proposed, should be reviewed on the basis of new information available, before final values for standards are accepted.

Appendix I. European Standards of Motor Rating

Comparison of French,[6] British,[7] and German[8] with American standards reveals considerable differences in both torque and temperature limits for general-purpose a-c motors. The quantity of work-performing ability measured by one continuous horsepower of motor rating cannot be accepted as an international standard, therefore, but must be evaluated by reference to the customs in the country of origin.

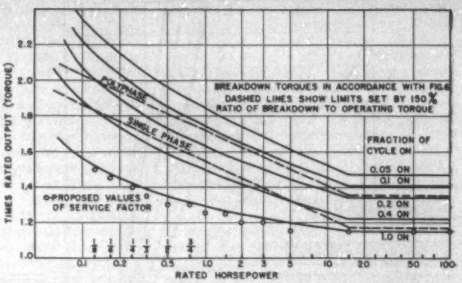


Figure 10. Permissible overloads of typical four-pole general-purpose a-c motors in intermittent service, in 40 degrees centigrade ambient

All four countries give general-purpose industrial motors a single continuous rating, limited by temperature rise. The first three countries allow a maximum ambient temperature of 40 degrees centigrade, but the Germans allow 35 degrees centigrade ambient. American and British rules for open-type motors specify 40 degrees centigrade rise by thermometer; while French rules specify 55 degrees centigrade by resistance, or 50 degrees centigrade by thermometer if resistance measurements are not practicable, and German rules specify 60 degrees centigrade by resistance or thermometer, whichever gives the higher reading. In all cases, temperatures are measured before and after shutdown, the highest reading being taken and no tolerances from the guaranteed values being allowed.

For these open-type low-voltage motors, it is fair to say that the hot-spot temperature rise is not more than 25 per cent above the thermometer reading, or 12 per cent above resistance measurements. On this basis, the hot-spot temperature rises of the four motors at rated load will be 50 degrees, 50 degrees, 62 degrees, and 67 degrees centigrade, respectively. In continuous operation at full load in a 40-degree-centigrade ambient, therefore, the American and British motors will have a life expectancy of 25 years, the French motor 10 years, and the German motor 6 years, from figure 1, assuming the same design margins over guarantees. American special-purpose motors, or general-purpose motors operated at their 115 per cent service-factor rating, however, have the same temperature rise, and the ten-year life expectancy, of the French motor. In a 35-degree-centigrade ambient, these periods would all be increased about 50 per cent.

For totally enclosed motors, the American rules allow 55 degrees centigrade rise by thermometer without any service factor, and the British allow 50 degrees centigrade, while the French and Germans keep the same 55- and 60-degree rises by resistance allowed for open motors. In a 40-degree-centigrade ambient with continuous operation at rated load, these correspond to life expectancies of five, ten, ten, and six years, respectively, the American having the shortest life in this case.

The five-degree spread between open and closed motors under the American rules may be justified technically on the grounds of a lower hot-spot differential, slower deterioration of insulation from other causes than temperature in enclosed motors, and the frequent use of these motors in outdoor installations at lower ambients. It is economically sound, because it is relatively a great deal more expensive to lower the temperature of a fully enclosed motor than of an open motor, and because it facilitates interchangeable mounting dimensions for open and closed motors.

The inherent, or short time, capacity of a motor is determined by its maximum torque, which is quite independent of the temperature rise. For a true comparison of an induction motor's ability to handle all sorts of loads, therefore, it is necessary to know its breakdown torque.

The American and British rules both specify a minimum of 200 per cent breakdown torque, or 100 per cent overload torque, for standard general-purpose industrial motors. The French rules require only 150 per cent, and the German rules 160 per cent breakdown torque, on the basis of continuous ratings. The French rules recognize seven, the British two, and the German four kinds of intermittent or short-time ratings, for which 200 per cent breakdown torque is required by all except the French rules. None of the rules prescribe any starting-current limits for industrial motors.

The breakdown-torque values, which are the best measure of magnetic dimensions and mechanical ability, indicate that the standard American, British, French, and German continuous-rated motors have relative sizes of 100, 100, 75, and 80, respectively.

The American, British, and French all have special rules for fractional-horsepower motors, which cover motors smaller than one horsepower at 1,500 rpm, one horsepower at 1,000 rpm, and 600 watts, respectively. American rules prescribe the same breakdown torque and temperature limits as for larger motors, except that 175 per cent breakdown torque is required for single-phase motors. British rules require only 125 per cent breakdown torque for polyphase and 100 per cent for single-phase motors. They also extend the 50-degree temperature-rise limit to include drip-proof as well as totally enclosed motors, keeping 40 degrees centigrade for open motors. French rules provide a special "domestic" service rating for fractional motors, which is defined as equivalent to continuous service

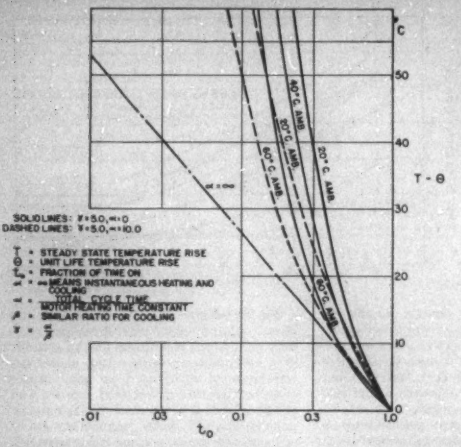


Figure 11. Permissible excess temperature rise in intermittent service, for fixed total insulation life (showing effect of cycle time compared to heating time constant)

at two-thirds of the name-plate horsepower, implying a breakdown torque 225 per cent of the continuous capacity. The French also provide a higher temperature rise for all fractional-horsepower motors, 65 degrees centigrade for continuous-rated motors, and 85 degrees centigrade for domestic motors for temperate climates, the latter on the basis of a maximum ambient temperature of only 20 degrees centigrade.

It is thus evident that continental standards call for materially smaller motors for a given continuous rating than American and British standards. R. Langlois-Berthelot has recently written a comprehensive article[5] on the temperature life of electrical machines, including an historical summary of the subject. His views on the normal life of insulation are summarized in the following statements:

> We shall take . . . the (hot spot) temperature θ (for rating purposes) as that permissible in a machine to assure in practice a normal life of 15 to 20 years, and we shall assume as a fact of experience that this normal life is equivalent to continuous operation for two years, or 17,000 hours, at the maximum temperature; so that . . . θ will correspond on the insulation-life curve to a life of two years. These are the average normal conditions, which take account of the usual variations of ambient temperature and of load. This interpretation of the temperature θ conforms to experience with machines and to the opinion of known experts who have been willing to express their views.

This point of view that the standards ought to set temperature limits to give long life under average conditions of reduced load and reduced ambient appears fundamental in continental standards, in strong contrast to the American viewpoint that the rated temperature should be low enough to assure a long life in rated load operation at the maximum ambient temperature.

Appendix II. Determination of Permissible Insulation Temperatures

In accordance with the experimental evidence that insulation deteriorates at a rate that is greater the higher the temperature, it is evident that, for the same useful life, a motor which is to be in operation only a part of the total time may be allowed to run hotter than a motor which is to be used continuously. In the body of the paper permissible overload durations were established, to secure the same total insulation life as at continuous full load, under the assumption of instantaneous heating and cooling. In practice, the motor takes an appreciable time to heat up, thus lowering the temperature in the initial part of the overload period, so that the actual temperature aging for the duty cycle is less than that assumed. In this appendix, the effect of this time lag of the temperature on the permissible duration of overloads will be considered.

It is assumed that the mode of variation of class *A* insulation life with temperature is that shown in figure 1*B*, which represents generally accepted data. According to this curve, the effective insulation life is given by:

$$L = L_0 e^{-a(T-\theta)} \qquad (1)$$

where

L_0 = years of useful life at some reference temperature
= seven years at 105 degrees centigrade continuously

$T - \theta$ = temperature of insulation above reference temperature

a = a constant, here equal to 0.0866 (degrees centigrade)$^{-1}$

Then the *rate of deterioration* of insulation must be of a reciprocal form.

$$R = Ae^{+a(T-\theta)} \text{ (where } A \text{ is a constant)} \qquad (2)$$

For the economic use of the temperature-life characteristic of the insulation, it is necessary to choose a temperature which, if maintained continuously, will allow a reasonable insulation life, henceforth to be called *unit life*, and then so to order the temperature duty cycles as to arrive at this unit life, no more, no less. This unit-life temperature is taken as 102 degrees centigrade (giving a unit life of about nine years), since this is closely the temperature attained by a standard general-purpose polyphase open induction motor having 40 degrees centigrade rise by thermometer at full load (50 degrees centigrade rise at hot spot), when running at the 115 per cent service factor load in a 40-degree-centigrade ambient temperature. The difference between this unit-life temperature (102 degrees centigrade) and the ambient temperature is called the *unit life temperature rise* and denoted by θ.

For the purposes of the present discussion the only type of load duty cycle which will be considered is the on-off type, such as experienced by a motor driving a refrigeration or air conditioning load. This assumes a load essentially constant to be applied for some fraction of the total cycle time, following which the motor is shut down for the remainder of the cycle.

To simplify the analysis only two types of temperature variation with load will be discussed: first, where the temperature instantly attains its steady-state value corresponding to the load applied, and, second, where the temperature varies exponentially, growing and decaying according to time constants which are characteristic of the particular motor.

Consider the case in which the temperature of the insulation exactly follows the steady-state value corresponding to the load applied. The temperature duty cycle has the same appearance as the load duty cycle: a simple rectangle having a height T (temperature rise above ambient) during the fraction of the cycle that the motor is on, and zero height (ambient temperature), while the motor is shut down. Then, for this temperature cycle to give unit life it is necessary that the total deterioration of the insulation during on and off periods be the same as if the insulation had remained at the unit-life temperature rise θ. Then the following equation must be satisfied:

$$At_o e^{+a(T-\theta)} + At_f e^{+a(-\theta)} = A \times 1.0 \qquad (3)$$

where

t_o = fraction of cycle time motor is on (constant load)

t_f = fraction of cycle time motor is off

$t_o + t_f = 1.0$

Equation 3 has the effect of averaging the actual temperature variation into the steady temperature θ. With the usual values of θ this simplifies to:

$$t_o e^{+aT} = e^{+a\theta} \qquad (4)$$

which gives the *straight* lines shown on figures 2, 11, and 12, when plotting T or $(T-\theta)$ against log t_o. As indicated in the body of this paper, it is a simple matter to translate such curves into the equivalent load or current curves if the steady-state temperature versus load or current characteristics of the particular motor are known.

As it has been assumed that the rate of deterioration of insulation depends only upon temperature, the results calculated on the basis of the above equation are correct for cycles of any time length, whether one hour, or several years. Thus, it is evident that standard motors possess considerable inherent overload ability (may ex-

ceed their normal temperature rise), judging from thermal considerations alone.

Consider the case in which the temperature varies exponentially. (It is assumed that the variation of temperature while heating under constant load can be represented by *one* exponential curve, characteristic of the particular motor, and similarly for cooling.) For economic utilization of the thermal properties of the insulation, since the temperature now varies with time, a generalization of equation 3 may be written as

$$\int_0^1 A\epsilon^{+\alpha(\phi-\theta)}\,dt = A \times 1.0 \text{ (where } \phi \text{ is instantaneous temperature)} \quad (5)$$

or

$$\int_0^1 \epsilon^{\alpha\phi}\,dt = \epsilon^{\alpha\theta}$$

whence (3) is obtained if $\phi = T =$ a constant for the fraction t_0 of the total cycle time.

The actual length of cycle time must now enter the calculations. Note that with a finite time-constant (for heating or cooling) as the cycle time approaches infinity the conditions of the previous case (instantaneous heating and cooling) are approached. In order to include the cycle time, it will be convenient to define two dimensionless quantities: α equal to the ratio of the total cycle time to the motor time-constant for heating and β equal to a similar ratio for cooling. The ratio of α to β will be denoted by γ. The steady-state temperature rise corresponding to the load applied toward which the actual temperature climbs while the motor is on will still be denoted by T. Then, since the temperatures at the beginning and the end of the cycle must be the same, it can easily be shown that during heating (motor on) the temperature variation is given by:

$$\phi = T(1 - k_1\epsilon^{-\alpha t}) \qquad 0 < t < t_0 \quad (6)$$

and during cooling (motor shut down) by:

$$\phi = Tk_2\epsilon^{-\beta t} \qquad 0 < t < t_f$$

where

$$k_1 = \frac{\epsilon^{\beta t_f} - 1}{\epsilon^{\beta t_f} - \epsilon^{-\alpha t_0}}$$

$$k_2 = \frac{\epsilon^{\alpha t_0} - 1}{\epsilon^{\alpha t_0 + \beta t_f} - 1}\,\epsilon^{\beta t_f}$$

Equation 5 then becomes:

$$\epsilon^{\alpha T}\int_0^{t_0} \epsilon^{-\alpha T k_1 \epsilon^{-\alpha t}}\,dt + \int_0^{t_f} \epsilon^{\alpha T k_2 \epsilon^{-\beta t}}\,dt = \epsilon^{\alpha\theta} \quad (7)$$

which reduces to (3) for $\alpha = \beta = \infty$. Fortunately, for the purposes of calculation equation 7 can be further reduced to a function of the "integral exponential" (E_1) for which tables of values exist. Thus:

$$\frac{\epsilon^{\alpha T}}{\alpha}\left[E_1(-aTk_1) - E_1\left(-aTk_1\epsilon^{-\alpha t_0}\right)\right] + \frac{1}{\beta}\left[E_1(aTk_2) - E_1(aTk_2\epsilon^{-\beta t_f})\right] = \epsilon^{\alpha\theta} \quad (8)$$

Although this decidedly is not an explicit relation for T as a function of α, β, t_0, and θ, by dint of successive trials, the representative curves of figures 11 and 12 may be drawn.

In brief, the calculations demonstrate that under usual ambient conditions and with a reasonable variation between actual heating and cooling time-constants of motors used on normal time cycles the effect of assuming instantaneous variation of temperature with load is more conservative than necessary.

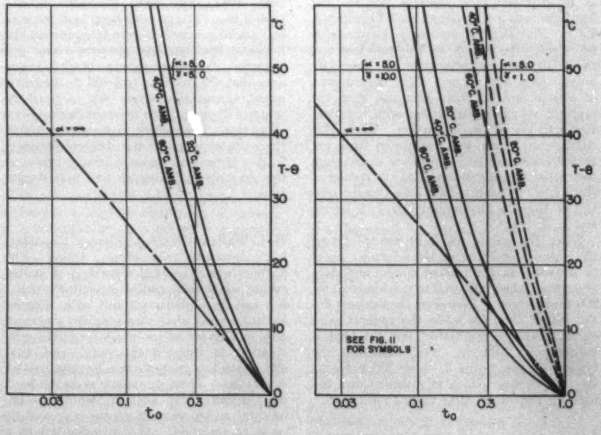
A typical small motor in the range from one-half to five horsepower will have a heating time constant of the order of ten minutes. With usual repetitive duty cycles of two hours or longer duration, therefore, the value of α will be of the order of 10 or more. The cooling time constant, with the motor at standstill is usually about five times as long as for heating. Thus, we may assume $\alpha = 10$ and $\gamma = 5$ as fairly typical values in service.

The effect of considering the thermal time lag of insulation is to allow a greater overload to be carried for the same duration or the same overload for a greater fraction of the total cycle time, as may be seen by referring to figure 11. For a temperature excess of $T - \theta = 25$ degrees centigrade (corresponding to 140 per cent current for a standard motor at 40 degrees centigrade ambient) a typical small motor ($\alpha = 10$, $\gamma = 5$) could permit an overload duration of 0.23. This is to be compared with the maximum duration of 0.33 which could be allowed if the cycle were so short that the temperature did not vary ($\alpha = \infty$), and to the value of 0.115 which would be recommended on the instantaneous heating basis ($\alpha = 0$) proposed in the body of the paper. The recommended values, therefore, make ample allowance for variations from usual conditions and this margin decreases only slowly as the cycle time is increased. Figure 12 shows the relative effects of heating and cooling time constants. Increasing γ means increasingly slower cooling which, therefore, loses part of the advantage gained by the temperature lag while the motor was on. Anything which tends to equalize the rates of heating and cooling increases the allowable duration of overloads. A change from the typical condition of $\gamma = 5$ to equal rates of heating and cooling ($\gamma = 1$) for a temperature excess of $T - \theta = 25$ degrees ($\alpha = 5$, and 40 degrees centigrade ambient) increases the allowable duration from 0.31 to 0.50, as compared with the recommended value of 0.115. The extreme case of $\gamma = 10$, which shows some decrease in allowable time from the recommended values is quite unlikely in practice.

Offsetting this gain from time lag in heating is the temperature creep due to increased copper resistivity at elevated temperatures. From figure 11, for a typical case of $\alpha = 10$, $\gamma = 5$, 40 degrees centigrade ambient, thermal lag increases the allowable temperature rise for a cycle 15 per cent on and 85 per cent shut down, from 84 degrees centigrade to 105 degrees centigrade, or by a factor of 1.25. On the other hand, figures 4 and 7 indicate that on a continuous load, allowance for creep requires that the expected rise be set at only 93 degrees centigrade, if 105 degrees centigrade actual rise is to be obtained. Thus, the effect of temperature creep largely offsets that of thermal lag for high overloads and long cycles.

By this analysis, therefore, simple methods have been derived for determining the limiting permissible overload duration for any heating constants and any length of duty cycle, making use of figures 11 and 12. The results indicate, however, that the simple curves of figures 2 and 5 are adequate for most purposes, the additional overload capacity due to thermal time lag being of importance only for duty cycles of two hours or less.

Figure 12. Permissible excess temperature rise in intermittent service, for fixed insulation life (showing effect of cooling time constant compared to heating time constant)



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Discussion

L. A. Kilgore (Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa.): The authors are to be commended for a scientific attack on this problem and their ultimate simplification of some involved data and theory. The conclusions, of course, are no more accurate than the original assumed relation between temperature and life of the insulation. While this data seems fairly well confirmed from experience with actual machines, it would seem somewhat optimistic based on the results of the paper, "Temperature Life Characteristics of Class A Insulation," by J. J. Smith and J. A. Scott.

Since the paper refers in several places to 15 horsepower and up, the inference might be drawn that the typical curves and data given applied equally well to machines above 200 horsepower. I am sure the authors did not intend this, for while the general principles given are applicable, still the typical values are different. For example, the typical curves, figure 3, show 180 per cent starting torque, which is several times too high for general-purpose class I motors.

L. E. Hildebrand (General Electric Company, Lynn, Mass.): There is a point common to my paper and that of Messrs. Alger and Johnson which should be explained. I refer to the per cent time on for intermittent cycles. The same thing is said in both papers. However, one who reads them hurriedly without noting a change in viewpoint may hastily infer that we do not agree. Their paper shows the per cent time on for various loads based on an ideal long cycle. This might be called short year service, meaning that the motor is operated a few months per year or a few days per month, but when it does operate, it reaches and maintains continuous temperature for a long time. In their appendix, they show corrections for shorter cycles.

In my paper I consider ideal short cycles to which they refer in the section "Permissible Intermittent Overloads." In the ideal short cycle, the on and off periods are so short and so frequent that the temperature does not rise above the average. The ideal short cycle essentially describes machine-tool jobs. It is expedient and clearer to consider such jobs from the root-mean-square load standpoint. If the cycle becomes so long that the temperature does rise a few degrees above the average, a simple correction can be made. Hence if the cycle is hours per day, use long cycle methods corrected for thermal log. If the cycle is minutes per hour, use short cycle methods corrected for temperature variations. Most machine tool cycles are so short that no correction is necessary.

The permissible "time on" for short-cycle jobs is much greater than for long-cycle jobs. A motor with proper winding will carry about 140 per cent base load, 30 per cent time on if the cycle is long, 66 per cent time on if the cycle is short. 175 per cent base load, 6 per cent time on for a long cycle becomes 43 per cent time on for a short cycle.

The motor described in the section "Characteristics of Motors Designed for Intermittent Service" by Messrs. Alger and Johnson is very close to the one-hour motor of the next higher standard rating if it refers to the lower horsepower range. It is good for 175 per cent base load, 6 per cent time on ideal long cycle. The more common application is say 130 per cent base load perhaps less, on 80 per cent or even less running idle between load periods starting every few minutes. The extra torque ability is insurance that the machine tool will do the infrequent abnormally severe job or that the motor will operate the machine during some short peak load which is distinctly higher than the average or the root-mean-square load. Thus, this motor is ideally suited to the majority of machine tool and similar jobs.

H. L. Wallau (Cleveland Electric Illuminating Company, Cleveland, Ohio): The authors are proposing a method of motor rating which will combine available starting and breakdown torques with thermal limits to yield what they consider a reasonable service life of ten years for either continuous or intermittent duty, and that stator-winding temperatures be measured by resistance. These proposals seem to have logic behind them, although whether a life as short as ten years is proper may well be open to question. The introduction of a service factor permits the continuing use of the nominal ratings to which industry is accustomed.

In their final conclusion the authors state in part, "the temperature-life curve of figure 1 . . . should be reviewed . . . before final values for standards are accepted." This is very important inasmuch as the test curves from which curve *B*, figure 1, is replotted, do not yield a probable life expectancy of seven years for continuous operation at 105 degrees centigrade, and the use of this seven-year expectancy is basic to the values set up in the paper.

The curves from which Montsinger's figure 11 is derived, are shown in figure 6, page 783, April 1930, AIEE Transactions. The three curves numbered 4, 5, and 6 in this figure when plotted on semilogarithmic paper, with time to the logarithmic scale, and extrapolated to zero tensile strength, show relative temperature-life expectancies under oil, as follows:

Temperature (Degrees Centigrade)	Approximate Life	
	Weeks	Years
90	900	18
100	360	7
110	170	3 1/4

Figure 11 as erroneously plotted indicates a life expectancy at 100 degrees centigrade of 11 years. For 105 degrees the correct indicated expectancy is of the order of five, not seven years. The plotting error was called to Montsinger's attention recently, as these data are reproduced on pages 261 to 263 of "Transformer Engineering," and the discrepancy was acknowledged.

A study of the individual curves of Montsinger's paper (figures 6 and 7) does not seem to warrant the statement that insulation in air will outlast insulation under oil. Curve 3 of figure 6 has a straight-line characteristic with a loss of tensile strength of one-half per cent per week, indicating an ultimate life of 200 weeks. This is for varnished cambric in air at 110 degrees centigrade. Curves 1 and 2 of the same figure for temperatures of 90 degrees centigrade and 100 degrees centigrade, respectively, have convex characteristics indicating a shorter life at these lower temperatures, and all three indicate shorter expectancies than the corresponding curves for this insulation under oil. Figure 7 shows similar discrepancies. It would appear that too few test data were available to Montsinger at that time to obtain results consistent with experience.

Much caution must be exercised therefore in the selection of the proper life expectancy of insulation before either standards or operating guides are formulated for industry, and it is quite possible that sufficient knowledge on this particular subject is not yet available.

Hubert H. Race (General Electric Company, Schenectady, N. Y.): The time-temperature relation of the deterioration of insulating materials is a very important problem to the designer and user of electrical apparatus and rightfully deserves the emphasis that has been given it at this convention. *Often the physical changes which make such deterioration evident are really indications of chemical changes which caused them, so that physical evaluations of deterioration are insufficient but should be accompanied by controlled chemical experiments.* Therefore it seems important to contribute to this symposium a short engineering statement of

Table I. Ratios of Rates of Chemical Change for Ten-Degree-Centigrade Intervals for Different Values of Heats of Activation (Q)

Q (Calories per Mol)	t_1 (Degrees Centigrade)	t_2 (Degrees Centigrade)	(k_1/k_2)
15,000	150	140	1.54
15,000	130	120	1.61
15,000	110	100	1.70
20,000	150	140	1.78
20,000	130	120	1.89
20,000	110	100	2.02
25,000	150	140	2.06
25,000	130	120	2.21
25,000	110	100	2.42

our knowledge of the general law expressing the temperature dependence of various physical and chemical phenomena. The most general statement of this law is

$$k = Ae^{-\frac{b}{T}} \tag{1}$$

This general relation holds for phenomena such as chemical reactions, chemical equilibriums, evaporation, temperature coefficients of viscosity, and electrical conductance in semiconducting crystals. For chemical reactions, the law was given by Arrhenius in the form

$$k = Ae^{-\frac{Q}{RT}} \tag{2}$$

where

k = a constant of a differential equation which defines the rate of the chemical reaction
A = an experimental coefficient
Q = the heat of activation in calories per mol
R = the gas constant = 1.986 calories per degree mol
T = absolute temperature in degrees Kelvin

Since the coefficients of the above equations have considerable significance from the general background of our theoretical and experimental knowledge, wherever possible new data showing temperature dependence of any kind should be examined in terms of this general relation. This can be done by plotting log (dependent variable) against $(1/T)$, which should give a straight line whose slope has physical significance.

Taking the logarithm of the ratio of k in equation 2 for two temperatures, we have

$$\log_e (k_1/k_2) = (Q/R)\,[(T_1 - T_2)/T_1T_2] \tag{3}$$

An approximate rule-of-thumb statement is that the rate of a chemical reaction doubles for a 10-degree-centigrade increase in temperature. This rule is illustrated in table I of this discussion, in which are given the ratios (k_1/k_2) of the rate constants of chemical reactions calculated from equation 3 for three sets of 10-degrees-centigrade intervals at each of three values of Q. For most chemical reactions, within the temperature range in which we are interested, Q lies between 15,000 and 25,000 calories per mol.

Equation 2, which has a large mass of chemical data supporting it, is different in form from the empirical relation given in equation 2 of the paper on "Rating of General-Purpose Induction Motors" by Alger and Johnson. The coefficients of their relation have no theoretical significance. However, by expanding equation 2 above in a series for $(T - \theta)$ it can be shown that neglecting second order terms gives the form of Alger and Johnson's equation 2, and that for the range of temperatures being considered the error in this approximation is less than five per cent. Therefore the two relations are equivalent within the experimental error.

Although the general validity of the above rule for chemical reaction rates is unquestioned, in any given insulation system a number of other conditions must be known before an estimate can be made of the effects of such chemical changes on insulation life. In service, continuous chemical changes may (*a*) improve, (*b*) have no effect upon, or (*c*) decrease the electrical quality of insulation, depending upon conditions. Examples of these three possibilities are numerous and may result from many different types of chemical change depending upon particular conditions, but for illustration a single reaction, that of continuous curing of varnish in stator coils in service, may give all three results in sequence.

Stator coils, to be assembled, must be flexible. Therefore the varnish used in making them is not completely cured to a hard rigid form. In service the chemical and physical changes called "curing" continue slowly, resulting in continuously improving electrical quality for some time. These gradual changes continue throughout the life of the insulation and even though they progress to the extreme where the varnish is very hard, brittle, and full of cracks they may not cause electrical failure if, for example, the apparatus is not exposed to moisture, and the basic insulation such as mica is not disturbed by vibration or excessive expansion and contraction. I helped to dismantle several of the original two-phase generators at Niagara Falls which were removed from service without failure, in which the organic insulation had been changed almost to dry dust but the machine had continued to operate as long as it was undisturbed. On the other hand these same changes might lead to early failure under more adverse conditions of service such as might be experienced by motors in mines or on shipboard.

The points I wish to emphasize in this discussion are: (1) chemical changes often underlie observed physical changes; (2) for this reason laboratory experiments on physical and electrical deterioration should be accompanied by chemical tests to determine causes; (3) experimental data showing temperature dependence should be examined in terms of equation 1 instead of being expressed in some other purely empirical form; (4) numerous specific conditions must be known before a conclusion can be reached as to the effects of such chemical changes on insulation life in any particular instance.

V. M. Montsinger (General Electric Company, Pittsfield, Mass.): I wish to discuss this paper from the broad question of nameplate rating versus output. My work has, of course, been concerned mostly with transformers in which temperature is the only limit to output.

AIEE Standards No. 13 at one time had the statement that the name-plate rating of transformers should not be exceeded whatever be the ambient. It is difficult to see how such a rule could be justified, but apparently some excuse for it was given. After getting rid of this rule in 1922 the way was open to recognize that name-plate rating and output may be entirely different. One of the first things we did in the rules was to permit one per cent overload continuously for each degree centigrade that the ambient is below the standard. On the other hand, if the ambient is continuously above the standard, permissible output was reduced accordingly.

This did not go far enough to meet the needs where short-time overloads (in excess of those permitted by the one per cent rule) are sometimes required to meet emergency conditions.

The next step was to set up permissible short-time overloads, ranging from short circuit of a few seconds to several hours time. To do this, however, required knowing, at least in a rough way, how short-time high temperatures affected the life of insulation. The tests reported in my 1930 paper showed that each time the temperature is increased eight degrees the rate of aging, of insulation immersed in oil, doubles.

Some of the data presented at this convention indicates that the eight-degree rule is too conservative; that is, it requires more than an eight-degree increase in temperature to double the rate of aging in air. I understand that someone in the Petroleum Institute presented a paper some time ago which showed that the deterioration of petroleum was doubled for each 8.5-degree-centigrade increase in temperature. I note that Messrs. Alger and Johnson used the eight-degree rule in their paper which, I feel, marks an important milestone in this question of rating versus output of rotating machinery.

I am not so much concerned in whether the eight-degree rule is absolutely correct, as I am in getting this fundamental method of analysis applied to electrical apparatus where temperature is the principal limit to output.

I do not want to give the impression that I am advocating that short-time overloads on rotating machinery be limited by temperature alone, as we have done for transformers, because there are limitations other than temperature for most classes of rotating machinery.

I do feel, however, that it is possible to go quite a ways yet in working out safe moderate overloads, as Messrs. Alger and Johnson have done. I venture the prediction that in a few years the name-plate rating of a large part of smaller rotating machinery will be used mostly for purchasing purposes, while the output will be more or less than the rating, depending on the operating conditions—the same as is true for transformers today.

C. G. Veinott (Westinghouse Electric and Manufacturing Company, Lima, Ohio): Messrs. Alger and Johnson recognize the same difficulty outlined in Mr. Rutherford's current paper ("Rating and Application of Motors for Refrigeration and Air-Condi-

tioning Systems," AIEE TRANSACTIONS, volume 58, 1939, see 1939 annual TRANSACTIONS index for page numbers) that the present horsepower ratings, particularly of fractional-horsepower induction motors, do not adequately describe the motor. Their proposal is to increase the service factor and leave the present horsepower ratings intact. This proposal would undoubtedly be acceptable to the refrigeration manufacturers since it effects no change in ratings, but does little to clear up existing confusion as to control and wiring. In general, the torque and current specifications given by the authors are acceptable as they are conservative values for present-day commercial capacitor-start motors. But these standards can not universally apply to split-phase motors. However, we see little point in reducing the locked-rotor current specifications for the one-eighth and one-sixth-horsepower sizes.

The whole subject of locked-rotor currents is one which may well concern AIEE whose membership includes the power companies who are as vitally interested in this subject as well as the motor manufacturers. The great disparity of requirements in this respect was brought to light by a recent survey of 51 leading public utilities in the United States. The maximum permissible locked-rotor current for a three-fourth-horsepower 220-volt single-phase motor allowed by each company was tabulated with the following results:

1 company specifies 12.25 amperes maximum
16 companies specify 20 amperes or less
29 companies specify 30 amperes or less
The National Electrical Manufacturers Association specification is 30.5 amperes
22 specify more than 30 amperes (of these 22, 13 have no specifications)

In other words, 29 of 51 companies have not accepted the value established by NEMA as the lowest value to which motor manufacturers can work without penalizing the motor design unnecessarily. Fortunately many of these 29 companies do not enforce their locked-rotor current rules. The few that do often work a hardship on the motor user, forcing the motor manufacturer to design and build special motors for certain localities. This procedure usually involves expense and inconvenience both to the manufacturer of the motor and the builder of the appliance, generally resulting that the customer who buys the motor-operated appliance has to pay more for a less satisfactory appliance than a more fortunate customer who is permitted to use the standard motor. Some standardization is urgently needed in order not to obstruct progress in the development of motor-driven appliances, and the resultant general increase in use of electric power.

T. C. Johnson: Two important ideas which are the natural outgrowth of the paper on "Rating of General-Purpose Induction Motors" just presented arise for discussion at this time. The first concerns the available torque of the general-purpose motor and the second concerns the relation between the service factor, frame size, and the ten-degree temperature rise margin.

The available torque of general-purpose motors is very important and therefore it is fitting to re-emphasize this point as made in the paper.

Under the competition of good design and the guidance of AIEE, NEMA, and ASA standards, a method of rating has grown up which specifies that a motor operated continuously at rated load under the most severe conditions will have a temperature rise of 40 degrees. The standards also specify that the motor must be capable of delivering 115 per cent of its rated output continuously without damage to itself and that it must have a maximum torque at breakdown of not less than 200 per cent of rated torque. Since due allowance must be made for possible voltage reduction and unexpected variations in the application, good practice requires that not more than 135 per cent of rated torque be demanded. However, all of this torque is available and should be used for economic application although the extent to which this overload torque can be used depends on the application since temperature rise is an additional limitation.

Considerations of available torque lead to a discussion of the service factor and its relation to the rating of successive frame sizes. The service factor is most simply defined as

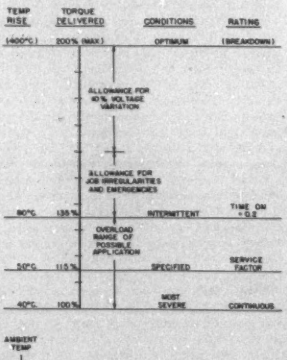

Figure 1. Available torque of integral-horsepower motors (15–200 horsepower)

the ratio of the maximum continuous load that can safely be handled to the rated continuous load. Under the present standards this corresponds to the ratio of the output with a 50-degree rise to the output with a 40-degree rise. The possible difficulties due to the service factors increasing in size for the smaller-horsepower motors, as shown in the paper, may be removed by considering the service factor as a simple measure of the step in rating between successive frame sizes. For integral-horsepower motors which have an average step in rating of 30 per cent between successive frame sizes, the service factor, defined as before, is equal to 1.15 and corresponds therefore to a step of one-half frame size in rating.

For fractional-horsepower motors the case is very similar. A small motor has higher breakdown torque than a large motor for the following reasons: (1) the steps in rating between frame sizes are larger in order to cover the range economically, (2) the uncertainties in application are a greater percentage of the output, (3) the power factor is naturally poor, (4) applications are most commonly intermittent.

For these reasons the service factor, again defined as the 50-degree rating over the 40-degree rating, for small motors is equal on

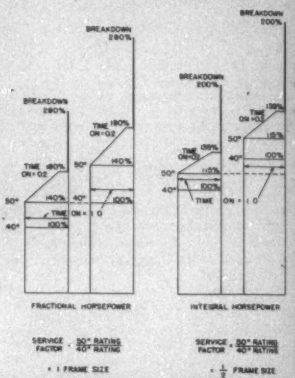

Figure 2. Relative output of successive frames

the average to 1.4. Since the average step in frame size horsepower for small motors is about 40 per cent, the service factor may most simply be thought of as a step of one frame size in rating.

These two points of available torque and service factor are summarized on two figures. In the first figure the bottom line represents, operation at rated output, 40-degree rise, 100 per cent load, continuous service under most severe conditions. The next line above represents operation at the service factor rating, 50-degree rise, continuous operation. The top line represents the breakdown torque. Making allowances as shown for voltage variation and mechanical emergencies, there is left 135 per cent rated torque to be used. For a load which is on only two-tenths of the total cycle time, this full 135 per cent torque can and should be used for economic application.

On the second figure is shown the relative output of successive frame sizes, first for integral-horsepower motors where the 1.15 service factor corresponds to an increase in rating of one-half frame size and second for fractional-horsepower motors where the average service factor of 1.4 corresponds to a step of one whole frame size. The relative widths in the diagram correspond to the approximate times for which the corresponding torque can be utilized with safety. Thus the service factor may very conveniently be related to the step in rating between successive frame sizes.

P. L. Alger: We appreciate the comments of Messrs. Race and Montsinger, who agree with our use of the simple law of about half life for each eight-degree increase in temperature, as a practical way of expressing the effect of temperature on insulation. The actual life obtained on any given motor depends in a very high degree on the particular conditions met with, such as the

ambient temperature, the load cycle, and especially the degree of dirt, moisture, vibration, etc. The use of the law is rather in estimating the effect of a temperature change on insulation life, found by experience in particular conditions, than in estimating the life under totally new conditions.

Answering Mr. Wallau's statement that our curve *B*, figure 1, is not an exact representation of Mr. Montsinger's 1930 test data, the curve does represent an over-all average of experience, of which the particular tests reported by Mr. Montsinger are only a part. The important conclusion is that the 105-degree-centigrade limiting hot-spot temperature for class *A* insulation has been found generally satisfactory in industrial service.

In reply to Mr. Kilgore's comment, the curves in the paper are intended only to cover general-purpose motors—that is, 200 horsepower and smaller at 450 rpm and higher speeds. The starting torques are assumed to correspond to the NEMA standard of 150 per cent of full load torque for four-pole motors. The 180 per cent value for the 25-horsepower motor shown in figure 3 provides a reasonable margin over this 150 per cent guaranteed figure.

Mr. Veinott points out the wide variation in starting-current requirements of different power companies and emphasizes the importance of having such adequate standards that the motor name-plate conveys a definite description of the motor's performance. This is very pertinent, as, under present conditions, many small motors are operated at loads greatly in excess of their name-plate values, and this leads to a great deal of uncertainty about the proper control and wiring.

There are two possible ways of procedure. One is to have a great number of special motors designed for particular services, each with a name-plate horsepower and time period of rating exactly representative of the expected motor performance. Such motors would naturally have a low ratio of maximum to full-load torque and would have a relatively low starting current per rated horsepower. The other procedure is to have a limited number of special motors of the foregoing closely rated types, and in addition to have a standard general-purpose type of motor suitable for operating under any one of a wide range of conditions. Such general-purpose motors, however, would naturally be used at widely different values of horsepower, depending on the intermittency of load, the ambient temperature, the desired life, and other conditions. If such motors are used, it is logical to give them a single conservative rating, representing the output the motor can always be relied upon to deliver under severe conditions; and, in this case, such motors will have relatively high starting and breakdown torques, high starting currents, and considerable overload ability, which will be used in many applications. The permissible starting current should, therefore, be based on the service-factor rating of the general-purpose motor, to be consistent with the rules for closely rated special-purpose motors.

In conclusion, I wish to point out again that this paper is intended to give a better understanding of the range of possible application of a standard general-purpose motor which, without change in name plate, is admirably fitted to a wide range of uses.

Determination of Temperature Rise of Induction Motors

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Synopsis: The "American Standards for Rotating Electrical Machinery" (American Standards Association) prescribe that the temperature rise of motors shall be measured by the thermometer method for purposes of rating. Definite limiting values of temperature rise are established for each type of machine. The AIEE Standards No. 1 fix conventional allowances of 15 degrees centigrade, 10 degrees centigrade, and 5 degrees centigrade between the actual hottest-spot temperature and the highest observable value of temperature as determined by thermometer, resistance, and embedded-detector methods, respectively.

This paper presents information on the relations between the measured values of temperature rise by different methods as found in tests on several hundred induction motors ranging from 10 to 1,000 horsepower in rating. It is shown that, with modern motor construction, variations of 20 degrees centigrade or more are sometimes obtained by the thermometer method on a given machine depending on location of thermometers or thermocouples, whereas the resistance measurements give relatively consistent values of temperature rise.

It is therefore suggested that the standards for temperature-rise measurements be revised, and that the resistance method be adopted for all forms of enclosed or protected machines which are not readily accessible for application of thermometers on laminations, insulated windings, and other adjacent parts.

TEMPERATURE rise is more frequently a limiting feature than is any other single motor characteristic in determining the maximum horsepower ratings that may be obtained from a given induction-motor frame size. Dependable heating data are of primary importance, because the probable length of insulation life diminishes rapidly at excessive winding temperatures. Procedures for obtaining motor temperature measurements are not well standardized at the present time, and the reliability of heating data cannot be satisfactorily evaluated unless the fidelity and accuracy of testing methods are known.

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The objects of this paper are (1) to suggest revision of the present induction-motor standards to place temperature measurements on a better basis, (2) to present test data which illustrate the need for and justification of these revisions, and (3) to suggest new temperature ratings of motors on basis of using the resistance method of determining temperature rise.

AIEE Standards No. 1 dated April 1925, recognize three fundamental methods of temperature determination which are defined respectively as the thermometer, resistance, and embedded-detector methods. Rules governing the interpretation of these different methods are quoted from paragraph 1–7 of the standards:

1–7 Limiting Observable Temperatures and Conventional Allowances. Limiting "observable" temperatures are deducted from the limiting "hottest-spot" temperatures by subtracting therefrom a specified number of degrees which, FOR PURPOSES OF STANDARDIZATION, is the margin fixed between the limiting hottest spot and the limiting observable temperatures.

This margin is designated as the "CONVENTIONAL ALLOWANCE."

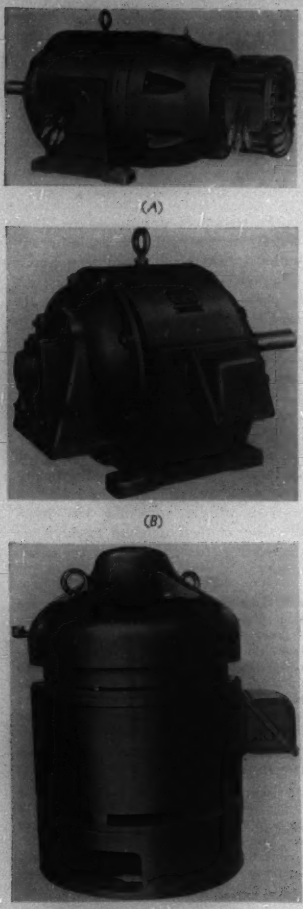
The specified differences (which may be designated the "Conventional Allowances") by which the "observable" temperatures are, FOR PURPOSES OF STANDARDIZATION, assumed to be lower than the "hottest-spot" temperatures, are as follows:

Thermometer Method—
15 degrees centigrade

Resistance Method—
10 degrees centigrade

Embedded-Detector Method—
5 degrees centigrade

On the basis of the standard 105-degree-centigrade limiting "hottest-spot" temperature, the maximum "observable" temperature must not exceed 90 degrees centigrade by thermometer for class *A* insulation; and from this were derived the present limiting ratings of 50 degrees centigrade rise by thermometer above the standard 40 degrees centigrade ambient for special-purpose open motors, and 40 degrees centigrade rise combined with a 1.15 service factor for general-purpose open motors. The "conventional allowances" for "hottest-spots"



(A)

(B)

(C)

Figure 1. Typical induction motors of modern construction which are not readily accessible for thermometer measurements

(A) Totally enclosed fan-cooled wound-rotor type, (B) splashproof type, and (C) vertical motor for outdoor service

have generally been considered as five degrees centigrade less for totally enclosed than for open motors because the windings of the former are heated more uniformly, and from this premise the maximum rating of 55 degrees centigrade rise by thermometer above a 40 degrees centigrade ambient was adopted for totally enclosed motors.

Paragraph 5.050 of the ASA *C-50* standards approved on January 6, 1936 (subsequently to adoption of AIEE Standards No. 1) specifies that all temperatures of induction motors shall be determined by thermometer method. ASA rules 2.055 and 2.063 relative to thermometer method are as follows:

2.055—*Thermometer Method of Temperature Determination Defined.* This method consists in the determination of the temperature by mercury or alcohol thermometers, by resistance thermometers, or by thermocouples, any of these instruments being applied to the hottest part of the machine accessible to mercury or alcohol thermometers.

2.063—*Measurement of Machine Temperatures.* As far as practicable, temperature measurements shall be taken during the test, without making any change in the machine which will affect the results, as well as immediately after shutdown. The temperature of totally enclosed motors (including totally enclosed fan-cooled motors) shall be obtained after shutdown by applying the thermometer to the hottest part of the machine which can be made quickly accessible by removing covers. If the core and windings are not accessible such as in totally enclosed or totally enclosed fan-cooled motors, holes must be provided through any intervening structural parts to permit the application of the thermometer method.

The highest measurements obtained shall be the accepted values.

The location of the hottest observable point in a motor actually depends on a number of factors such as the enclosing features if any, type of winding and insulation treatment, arrangement of fans and air deflectors, number and size of air ducts, relative proportions of component losses, etc. No standardized thermometer locations would be suitable for all types of motor construction. Consequently the test results by thermometer method may or may not be representative of actual maximum temperature rise depending on familiarity of testing personnel with motor characteristics, and also on whether a conscientious effort is made to locate the hottest observable point in the machine. The term "accessible" is also subject to individual interpretation and cannot be sharply defined.

A different arrangement of thermometers may occasion a wide disagreement in test results when the same motor is tested by two different parties, and these variations are frequent sources of controversy. The testing situation is becoming increasingly complicated because of the definite trend toward more enclosing features in the design of induction motors. A large percentage of modern motors now has a mechanical construction which either reduces or eliminates entirely the accessibility of internal parts as illustrated by figure 1.

To clarify this unsatisfactory situation with respect to temperature measurements, testing methods should be modified in accordance with changes in motor construction, so that comparable results may be obtained when the same machine is tested by two different organizations. This paper recommends general recognition, adoption, and standardization of the resistance method. Results of many tests are presented to prove that the winding resistance gives a more reliable indication of actual insulation temperature than measurements made with thermometers.

Some Specific Situations for Which the Present ASA Standards Are Inadequate

Specific test results and situations are presented to illustrate the inadequacy of the present ASA standards relative to heating tests.

1. Totally Enclosed Fan-Cooled Motors

Reliable winding temperature data usually are not obtained by thermometers inserted through holes bored in the frame of an enclosed motor as directed by ASA rule 2.063.

A test made on the totally enclosed fan-cooled motor designated as *X* in appendix I and table I, where the stator winding was explored by placing 28 thermometers and thermocouples at different points as indicated in figure 2, shows variations of 22 degrees centigrade (27 degrees centigrade to 49 degrees centigrade) in temperature rise, on the surfaces accessible to thermometers. A maximum variation of 32 degrees centigrade (27 degrees centigrade to 59 degrees centigrade) is obtained by including the inside surfaces of coil ends which are accessible to thermocouples but not to thermometers inserted through holes bored in the frame.

2. Multiwinding Motors

On multispeed motors having more than one stator winding, thermometers usually cannot be placed on the underneath winding. The lower-speed winding is almost invariably located inside next to the air gap. Because of reduced ventilation this lower-speed winding usually has the higher temperature rise, especially on constant-horsepower and constant-torque ratings. Thermometer measurements taken on the outside idle

winding may be from 10 degrees centigrade to 20 degrees centigrade lower than the actual temperature of inside active winding. Confirming tests are described in appendix II, and the test data are presented in table II. With the "sandwiched" type of coil construction, the inside winding may not be accessible for either thermometers or thermocouples. The ASA standards do not have any satisfactory provisions for testing multiwinding induction motors. On open as well as enclosed multiwinding motors, only one winding is usually accessible for the thermometer method; consequently this criticism of the present standards applies to all types of mechanical construction.

3. Wound-Rotor Machines With Inaccessible Rotors

No provisions are made in ASA standards for rotor temperature measurements of totally enclosed wound-rotor motors of the form shown in figure 1. With this construction the rotor winding is usually the limiting feature, because its temperature rise is commonly 10 degrees centigrade to 20 degrees centigrade above that of the stator. On all forms of totally enclosed as well as on most splashproof wound-rotor machines, the insulated rotor winding is completely inaccessible to the thermometer method when outside enclosed collectors are used. The provision of paragraph 2.063 of ASA standards for "applying the thermometer to the hottest part of the machine which can be made quickly accessible by removing covers" is certainly not applicable where it becomes necessary to practically disassemble the machine in order to gain access to at least one end of the rotor winding. Such a major disassembly of large machines requires so much time that subsequent temperature readings are of little significance. In field tests it may not be possible to disassemble the motor.

4. General-Purpose Motors

Although general-purpose motors with open-type construction are more accessible for application of thermometers on the windings and laminations than the types of machines cited in the preceding paragraphs, nevertheless, there is considerable variation in the results which may be obtained by different parties due to varying locations of thermometers. Appendix IV and table IV present results of tests made on motors of 12 different manufacturers, and five of these machines showed a temperature rise higher than the name-plate stamping. It, therefore, seems most probable that this situation is a result of variations in testing procedure which may now occur under the present standards.

5. Explosion-Proof Motors

Although the Underwriters do not actually forbid the boring of holes for thermometers in explosion-proof motors, such a practice is dangerous and undesirable; because any failure to plug a hole securely might result in an explosion external to the motor after the machine is placed in normal service. The present standards as worded therefore may create a potential hazard when tests are taken on explosion-proof machines.

Summary of Test Results by Resistance Method

To investigate and demonstrate the dependability and consistency of the resistance method of measuring temperature rise, an analysis was made of approximately 300 heating tests on various types of polyphase induction motors over the range of sizes from 10 to 1,000 horsepower. Temperature rises were measured both by the resistance method and also by thermometers (or thermocouples). The test results may be summarized as follows:

1. On totally enclosed and totally enclosed fan-cooled motors, the stator temperature rise by resistance method is essentially the equivalent of that obtained by thermocouples applied at hottest part of winding surface. On the basis of averages, the thermocouples checked the resistance method within 1.1 degrees centigrade (48 degrees centigrade–46.9 degrees centigrade) for the 65 tests on totally enclosed fan-cooled motors, and within 0.6 degrees centigrade (40.1 degrees centigrade–39.5 degrees centigrade) for the 26 tests on totally enclosed motors which are tabulated in table III. To locate the hottest winding surface, some of the thermocouples were placed at points which were not accessible to thermometers inserted through holes in stator frame as explained in appendix III.

2. On open-type or partially enclosed splashproof (or dripproof) machines rated 2,200 volts or less, heating tests on 149 different motors as described in appendices III and IV indicate about two degrees centigrade less average stator temperature rise by the resistance method than by thermometers (or thermocouples at locations which could have been reached by thermometers through holes in the frame) searchingly applied in accordance with the present ASA standards. (The 149 tests include the stator temperature measurements on the 41 splashproof and 96 open motors of table III and on the 12 open motors of table IV.)

3. Measurements taken on the 36 insulated wound-rotors of table III show an average temperature rise of 4.6 degrees centigrade (34 degrees centigrade–29.4 degrees centigrade) more by change in resistance than by thermometer. Lower and in general less accurate values of temperature rise are obtained with thermometers because: (*a*) thermometers cannot be placed on center of rotor laminations in most cases, (*b*) the rotor must stop turning before thermometers can be applied and they do not attain maximum indication until after resistance readings are taken, and (*c*) rotors of many motors are not readily accessible and good thermometer contacts cannot always be obtained.

4. The resistance method is consistently reliable for all speeds and time ratings. In table III the results are segregated according to motor poles over the range from 2 to 12 poles for the continuous-rated squirrel-cage motors. Heating runs of one hour or less are separated from the tests of longer duration.

5. The resistance method is dependable over a wide range of motor load and line voltage as demonstrated in appendix V, table V, and figure 4. Tests on a representative 25-horsepower motor for different conditions of operation show that the temperature rise by any method is approximately proportional to the total motor losses.

6. Maximum differences of about ± ten degrees centigrade between the thermometer and resistance methods have been observed in tests on individual machines. The resistance method may definitely indicate either a higher or lower temperature than thermometers depending on mechanical construction of motor, the two extreme conditions being:

(*a*). Motors with improperly proportioned ventilation may have local hot spots where

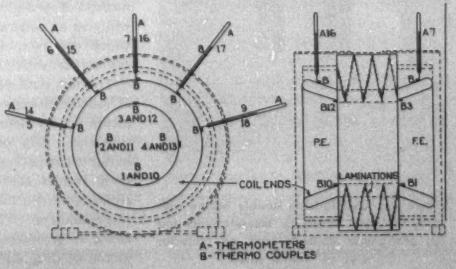


Figure 2. Location of thermometers and thermocouples on motor X

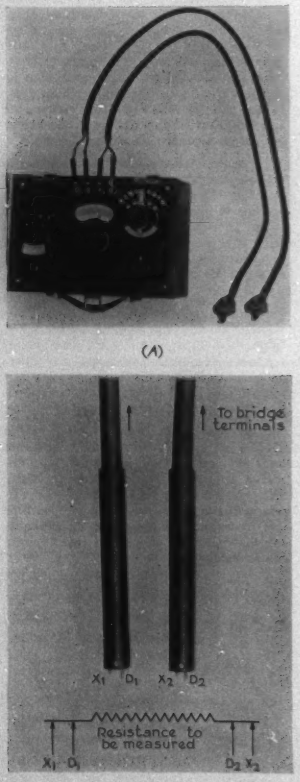
(Refer to appendix I and table I)

thermometer readings exceed resistance indication, but in many cases these hot spots are not located and explored by the thermometer method of test.

(*b*). High-voltage machines, especially 4,000 volts and above, usually (but not always) show a higher temperature rise by resistance than by thermometer because of the temperature drop in the coil insulation, in which case the resistance method is safer because it represents actual conditions.

Discussion

The thermometer method, as commonly used, is not a sufficiently definite procedure for determining the temperature rise of partially or totally enclosed motors, because it is probable that an insufficient number of thermometers will be used to locate the hottest point accessible to them. Wide variations in temperature may occur over a motor surface that appears to be uniform and symmetrical. The element of "chance" is therefore always associated to some extent with the thermometer method. On splashproof and other types of partially closed motors, thermometer readings may be as much as 10 degrees centigrade below the temperature of the hottest surface that might have been reached. Motor *K* of table IV in appendix IV is cited as a specific example wherein the actual maximum observable temperature rise of 61 degrees centigrade by thermometer was 11 degrees centigrade higher than the manufacturer's name-plate rating of 50 degrees centigrade—presumably because his test with thermometers did not locate the hottest spot.



(*A*) (*B*)

Figure 3. (A) Portable double bridge with leads for stator resistance measurements and (B) prong-type contacts used on collector rings of wound rotors

On totally enclosed machines where it is necessary to drill a separate hole in the frame for each thermometer, only a few are likely to be used—sometimes only one, and this increases the probability that the hottest part will not be located. Furthermore when thermometers are inserted in holes bored through intervening parts, it is usually impossible to cover the bulbs completely with pads or putty as specified in paragraph 2.056 of ASA standards. If only the end of thermometer bulb makes a point contact with the winding or laminations, the reading may be influenced by the surrounding air to which the bulb is exposed. As a practical result of all these factors, the trend toward more enclosing features on motors has been accompanied by increasing variations in the test results that are obtained by the thermometer method. Motor *X* of table I in appendix I is a striking example.

As the present standards do not insure reasonably accurate and consistent results when various motor types are tested by different organizations, it is therefore highly desirable to adopt a more convenient, more definite, and less expensive method of measuring temperatures which will give an accuracy comparable to that which can be obtained by a thorough exploration with thermometers.

The test data point to the desirability of standardizing on resistance measurements for the determination of temperature rise. For practically all types of motor construction, the resistance method gives results that are essentially the equivalent of a careful exploration with thermometers. The resistance reveals the average internal temperature of the motor winding and thereby gives a more reliable indication of actual insulation temperature than a few thermometer readings taken at isolated points on the outside surfaces of the coils.

The relation between winding resistance and temperature is a specific, definite physical law that is entirely divorced from the element of chance which is inherently associated with the thermometer method. The winding resistance can be measured quickly, conveniently, and at little cost. From the standpoint of comparative tests, the precision of the resistance method is limited only by the accuracy of resistance readings and the measurements of initial and ambient temperatures. Consequently it is believed that a general adoption of the resistance method will promote greater accuracy in testing, will assure the motor user of greater insulation life, will reduce controversy by making it possible for different organizations to obtain comparable test results, and will provide the motor user with a convenient method for taking field tests.

Precedents have already been established for recognizing the resistance method. The International Electrotechnical Commission European Standards, the United States Navy Specifications 17*M*10, and an increasing number of commercial customers now either accept or require the resistance method of testing to prove temperature-rise guarantees.

Although the resistance method requires accurate measuring devices and precision in testing procedure, experience indicates that these difficulties are minor compared to the benefits obtained when testing motors that do not have open-type construction. Readily portable instruments have been developed and are now available which have an accuracy that is satisfactory for motor temperature measurements. At least 95 per cent of the resistance data for the heating tests included in this report were obtained with a portable-type double-bridge arrangement similar to that shown in figure 3. The remainder of the readings were taken with the voltmeter-ammeter method by passing direct current through the winding. The portable double-bridge has proved very satisfactory in general testing work. It is readily carried, accurate, rugged, has a wide range of measurement, and is not easily thrown out of calibration. A description of this general type of bridge is given in an article entitled "The Portable Double Bridge" by L. O'Bryan in the *General Electric Review*, volume 34, 1931, page 752.

In common with most indicating in-

struments, the probable per cent error of measurement decreases as the upper end of bridge scale is approached. Bridges covering a range from 0.0005 to 4.4 ohms, and having a maximum probable error of 0.4 per cent in ohms (or about one degree centigrade) at most unfavorable part of scale that must be used, and a minimum probable error of 0.1 per cent at upper end of scale, have been found suitable for temperature measurements of motors between 10 and 1,000 horsepower for which data are presented in this paper. Bridges of this type can be made with various scales and scale multipliers to adapt them to different horsepower ranges of motors. Even though cumulative errors of 0.4 per cent in both the hot and cold resistance measurements do cause an error of two degrees centigrade in temperature rise, this is small compared to the error commonly made when a thermometer is inserted through a hole bored in the stator frame of an enclosed motor.

Errors due to contact drop in current circuit are minimized by using four leads to connect the unknown resistance to bridge terminals as shown in figure 3. Leads X_1 and X_2 carry the current which flows through the unknown resistance whereas D_1 and D_2 are potential leads. The voltage between D_1 and D_2 does not include the contact drops at X_1 and X_2. Part A of figure 3 shows the spring-type clips which are used for stator resistance measurements. The two contact surfaces of each clip are insulated from each other to provide separate voltage and current contacts.

Wound-rotor measurements are obtained with the contacts in part B of figure 3. The sharp prongs X_1 and D_1 are held firmly against one collector ring while X_2 and D_2 are placed upon another collector ring. Prongs D_1 and D_2 are supported on flexible coil springs which depress under pressure and thereby permit all prongs to maintain contact even though they are not held at right angles with collector-ring surfaces.

The following fundamental precautions will minimize testing errors and insure dependable heating data by the resistance method:

1. Use a bridge which is accurate within 0.5 per cent on lowest part of scale that must be used.

2. Calibrate the bridge periodically and keep the leads in good condition. Make sure that contacts are clean, and check galvanometer when readings are taken.

3. The persons taking resistance measurements should use all necessary precautions to obtain and record accurate data. A good check on the accuracy of results is obtained by having two different persons take readings with separate equipments. The two resistance readings should agree within 0.4 per cent (or about one degree centigrade).

4. Take resistance readings every minute for about ten minutes after motor stops and project the curve to zero time.

5. When taking "cold resistance" before the heat run, never assume that the motor temperature is the same as the ambient. Always place thermometers directly on motor. The motor may have been moved recently from another part of factory where temperature was different, the machine may not have cooled off completely from some previous manufacturing or testing operation, or the ambient temperature may have changed suddenly because of an open factory door. Accurate cold temperatures are just as important as accurate resistance readings.

6. Always take both hot and cold resistance measurements between the same two stator terminals or the same two rotor collector rings to avoid errors due to slight unbalance in phase resistances. If nonuniform heating is anticipated because of unbalanced power supply or unsymmetrical design, record resistance measurements of each phase separately.

Suggested Motor Temperature Ratings for Resistance Method of Test

If the resistance method of measuring temperature rise is accepted as standard, the question arises as to what temperature ratings by resistance shall replace the present 40-degree-centigrade, 50-degree-centigrade, and 55-degree-centigrade ratings by thermometer for general-purpose, special-purpose, and totally enclosed motors, respectively. The conventional "hottest-spot" allowance differentials in AIEE Standards No. 1 would suggest that all these ratings should be increased 5 degrees centigrade for the resistance method—namely to 45 degrees centigrade, 55 degrees centigrade, and 60 degrees centigrade. The test data show that, for any normal low-voltage induction motor, the resistance method is practically the equivalent of the thermometer method when thermometers are searchingly applied to locate the hottest observable part of the machine. The two methods agree within three degrees centigrade in most cases and seldom is the disagreement more than five degrees centigrade. The test results therefore indicate that an increase of not more than five degrees centigrade should be made in the present motor ratings to obtain the equivalent ratings by the resistance method. In fact, an increase of even five degrees centigrade must be justified partly on the grounds that more accurate results will be obtained by the resistance method than by thermometers as commonly used.

In actual practice over the past ten years, however, the points of measurement by the thermometer method have

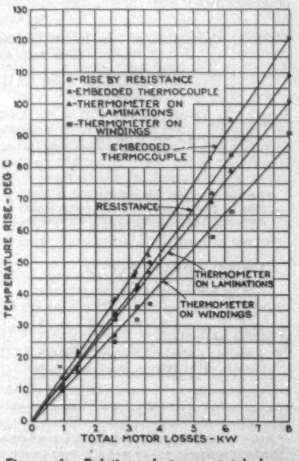


Figure 4. Relations between total losses and temperature rise by different methods of measurements for a typical 25-horsepower motor

(Refer to appendix V and table V)

not generally been the hottest surfaces. Hence, it is probable that 50-degrees-centigrade rise by resistance is a close approximation to the value that would be found by test on many partially closed motors now rated 40-degrees-centigrade rise by thermometer. The original 40-degree-centigrade rating was adopted in the standards on the assumption that thermometers gave values 15 degrees centigrade below the actual "hottest-spot" temperature; and when it is recognized that the resistance method gives test values that are approximately within 5 degrees centigrade below the hottest spot in many (but not all) motors, an argument is presented for adopting 50 degrees centigrade by resistance to replace the 40-degree-centigrade rating by thermometer.

To obtain confirming test data on the differentials between the internal "hottest-spot" and the limiting "observable" temperatures by different methods of measurement, thermocouples were distributed among the copper wires inside the stator slots when the random winding was installed in a typical low-voltage

25-horsepower motor as explained in appendix V. The heating tests on this motor, which are presented in table V and figure 4, show that for the three tests taken near normal load at 25.9, 26.4, and 25.8 horsepower, the corresponding differentials between the resistance method and the internal "hottest-spot" were six degrees centigrade, four degrees centigrade and five degrees centigrade, respectively—or an average differential of five degrees centigrade as compared to the present "conventional allowance" of ten degrees centigrade in paragraph 1–7 of AIEE Standards No. 1.

From the point of view of retaining the same limiting "hottest-spot" temperature of 105 degrees centigrade for class *A* insulation as originally intended in the standards, there is considerable justification for specifying 50 degrees centigrade by resistance in place of 40 degrees centigrade rise by thermometer in future standards. Such a step, however, might not leave sufficient margin for the conventional limits of voltage and frequency variation and for the 15 per cent service factor which are now specified in the ASA standards for general-purpose motors.

Similarly, 60 degrees centigrade and 65 degrees centigrade rise by resistance may ultimately replace 50 degrees centigrade and 55 degrees centigrade by thermometer for special-purpose and totally enclosed motors, respectively. However, a 65-degree-centigrade rating for class A insulation based on a 40 degrees centigrade ambient would not provide any margin for "hottest-spot" winding temperature. It may, therefore, be found desirable to accept 60 degrees centigrade instead of 65 degrees centigrade rise by resistance for totally enclosed motors, unless the standardized ambient temperature is reduced from 40 degrees centigrade to 35 degrees centigrade to be in closer agreement with prevailing temperatures in the United States. The long standing and justifiable precedent of rating open motors five degrees centigrade lower than enclosed machines may make it necessary to accept 55 degrees centigrade rise by resistance for special-purpose open motors, and in turn 45 degrees centigrade for general-purpose open motors, if 60 degrees centigrade by resistance is adopted as the temperature ceiling for totally enclosed construction.

Although the resistance method of temperature measurement is particularly adapted to inaccessible motors of partially or totally closed construction, test results demonstrate that it is also very satisfactory and dependable for open-type motors. However it may be desirable to retain the thermometer method in the standards for motors of entirely open construction, because it is the simplest possible procedure, and requires no special measuring equipment beyond the common mercury thermometer with which everyone is familiar. Even if resistance measurements are adopted as the standard method of testing and rating all types of motors, thermometers will still be needed for measurements of initial and ambient temperatures, bearing temperatures, for determining when the motor has reached a constant temperature, and for obtaining quick, approximate readings for check purposes.

Table I. Comparison of Two Totally Enclosed Fan-Cooled Motors of Different Manufacturers (See Appendix I and Figure 2)

	Front End				Pulley End			
Test Results for Motor X								
*Position—inside coil periphery	1	2	3	4	10	11	12	13
Rise by thermocouple—degrees centigrade	54	54	54	53	58	58	58	59
	Front End							
*Position—outside coil periphery	5	6	7	8	9			
Rise by thermocouple—degrees centigrade	27	41	39	30	27			
Rise by thermometer—degrees centigrade	39	43	38	29	27			
	Pulley End							
*Position—outside coil periphery	14	15	16	17	18			
Rise by thermocouple—degrees centigrade	47	47	47	48	49			
Rise by thermometer—degrees centigrade	46	46	48	48				
	Front End				**Pulley End**			
Test Results for Motor Y								
Inside coil periphery—degrees centigrade	50	50	51	51	49	51	51	50
Outside coil periphery—degrees centigrade	48	46	48	49	48	49	49	49

Temperature rise by resistance, motor *X*, one minute after shutdown 51 degrees centigrade.
Thermometers in positions 5 and 16 were not embedded in putty.
The other thermometers and all thermocouples were embedded in putty.
* Refer to figure 2 for locations of thermometers and thermocouples.
All above temperatures on motor *Y* were obtained with thermocouples.
Temperature rise by resistance, motor *Y*, 54 degrees centigrade.

Conclusions

To place motor specifications on a more sound basis, and to assure the motor buyer of more accurate and comparable temperature measurements, it is recommended that the resistance method of determining temperature rise be adopted as standard for all types of partially or totally enclosed induction motors, except for large, high-voltage machines for which the embedded-detector method should be retained.

It is also recommended that general industrial experience with respect to the present limits of temperature rise be reviewed, especially as regards "hottest-spot" allowances and differentials between various methods of measurement, so that the limits of temperature rise ultimately specified by the resistance method shall be in accord with the best interests of motor users.

The test data herein presented indicate that the new limits of rise by resistance should be at least five degrees centigrade above the present thermometer ratings for low-voltage machines with class *A* insulation. However, additional data and other considerations may indicate a ten-degree-centigrade increase to be logical, or may suggest separate temperature differentials for different voltage ratings or types of motor construction.

Appendix I. Comparison of Two Totally Enclosed Fan-Cooled Motors of Different Manufacturers

Comparative heating tests were made on two 75-horsepower totally enclosed fan-cooled motors having widely different construction features. These motors which are designated as *X* and *Y* were made by two different manufacturers. Both machines had the same NEMA frame number, speed, and horsepower rating, but motor *X* had a name-plate rating of 40 degrees centigrade rise whereas motor *Y* was rated 55 degrees centigrade.

Figure 2 shows the locations of 28 thermometers and thermocouples which were placed on the winding of motor *X*

through radial holes that were bored in the stator frame. One thermocouple was placed adjacent to each of the ten thermometer bulbs to obtain check readings. One of the thermometer bulbs on each end of the motor was not imbedded in putty in order to observe any difference in indication for this reason. Eight of the thermocouples were placed on inside periphery of stator coil ends directly over the rotor end rings. The values of temperature rise obtained at the different points for continuous operation at normal load are shown in table I.

By the thermometer method as defined in ASA standards 2.055 and 2.063, the temperature rise of motor X may be measured as anything from 27 degrees centigrade to 49 degrees centigrade depending on the number and location of points where readings are taken. The present standards do not specify the amount of exploration that shall be made to locate the hottest point accessible to thermometers. In this particular case the location and distribution of thermometers is of much greater significance than the details of how the bulbs are covered with putty or pads.

By placing thermocouples on the inside periphery of coil ends in positions not accessible to thermometers, higher values of temperature rise are obtained (53 degrees centigrade to 59 degrees centigrade).

The 51-degree-centigrade temperature rise of motor X by resistance method is only 2 degrees centigrade more than the maximum value of 49 degrees centigrade that could be obtained by following the ASA rules. If the testing personnel had used only two thermometers in positions 5 and 9, the temperature rise by the ASA rules would be measured as 27 degrees centigrade, or 22 degrees centigrade lower than the value of 49 degrees centigrade that might have been obtained.

On motor Y the temperature rise by resistance of 54 degrees centigrade is 5 degrees centigrade more than that obtained under the ASA rules, but is only 3 degrees centigrade above the values measured with thermocouples on inside coil periphery at points inaccessible to thermometers. The variation in temperature measurements by all methods on motor X is 32 degrees centigrade (59 degrees centigrade–27 degrees centigrade) whereas the corresponding variation on motor Y is only 6 degrees centigrade (54 degrees centigrade—48 degrees centigrade). The better uniformity of winding temperatures on motor Y is a result of a different type of winding and a more effective internal ventilation system. Consequently the thermometer method of ASA standards as usually applied would give results more nearly representative of maximum insulation temperature on motor Y than on motor X.

The tests on these two motors indicate that the temperature-rise-by-resistance method is much more dependable than thermometer readings which are obtained at a few points only. In this comparison the motor rated 40 degrees centigrade by thermometer actually had higher insulation temperatures than the 55 degrees centigrade rated machine. If the resistance method of test had been specified as standard, motor X definitely could not have qualified as a 40-degree-centigrade machine.

Appendix II. Multispeed Motors With More Than One Winding

If a motor has more than one stator-winding, surface temperature readings which are taken on the idle winding are of questionable value. It is common practice to place the winding with largest number of poles (and consequently the shortest end connections) inside next to the air gap. Even on open motors the underneath winding usually cannot be reached with thermometers, and it is utterly impossible to reach the inside winding of an enclosed machine by inserting thermometers in holes bored through the stator frame. Because of reduced ventilation at lower speed, the inaccessible winding is likely to be the limiting feature of the motor with respect to temperature rise on constant horsepower and constant torque ratings.

Table II shows thermocouple temperatures on both active and idle windings of three different four-speed motors having two stator windings. Machines M-1 and M-3 are of open-type construction, whereas M-2 is totally enclosed fan-cooled. Conditions of test including winding locations and temperatures of both active and idle windings are tabulated for nine different heating tests. Although a maximum difference of only 16 degrees centigrade appears on table II, differences up to 20 degrees centigrade have been observed.

Two-winding wound rotors are not very common, but when such construction is used at least one of the windings is likely to be inaccessible on open motors, whereas both are inaccessible to thermometer method on totally enclosed motors as well as on most splashproof motors.

When the "sandwiched" type of coil is used on a two-winding stator, the inner winding is in middle of slot whereas the outer winding occupies both the top and bottom positions. This inner winding is quite inaccessible to either thermocouples or thermometers.

To avoid misleading data, the resistance method of temperature measurement is recommended for all multiwinding motors.

Table II. Motors With Two Windings (Refer to Appendix II)

Symbol	Motor Rating
M-1	4/6/8/12 poles—60/40/30/20 horsepower—1,800/1,200/900/600 rpm—three phase—440 volts
M-2	4/6/8/12 poles—7.5/6.5/6/5 horsepower—1,800/1,200/900/600 rpm—three phase—440 volts
M-3	4/6/8/12 poles—50/33/25/17 horsepower—1,800/1,200/900/600 rpm—three phase—220 volts

	Conditions of Test			Temperature Rise—Degrees Centigrade	
Motor	Poles	Horsepower	Volts	Active Winding	Idle Winding
M-1	6	40	440	B...36	A...22
M-1	12	20	440	B...27	A...19
M-2	4	7.5	440	A...23	B...20
M-2	6	6.5	440	B...30	A...22
M-2	8	6	440	A...31	B...24
M-2	12	5	440	B...45	A...30
M-2	4	15	520	A...59	B...48
M-2	6	10	457	B...46	A...30
M-3	6	33	220	B...27	A...19

B—Indicates inaccessible underneath winding next to air gap.

A—Indicates outside winding farthest from air gap.

Appendix III. Analysis of Heating Data From Induction Motors Representing Various Types of Construction

In order to present a comprehensive analysis of the fidelity of the resistance method, a review was made of 264 heating tests made over a period of three years where temperature rises were measured by both the resistance and thermometer methods. The test data which are summarized in table III include a wide variety of motors representing different horsepower ratings, speeds, time ratings, electrical designs, and mechanical forms of construction. With the exception of a few of the wound-rotor measurements, each heating test was taken with a different motor. Approximately 70 per cent of the tests were made on motors in NEMA frame sizes from 364 to 505, inclusive. The remaining 30 per cent are for larger machines up to 1,000 horsepower. Several tests are averaged for each form of motor construction in order to minimize individual testing errors and thereby obtain a truly representative indication of results that could be anticipated by a general application of the resistance method.

All the surface temperature measurements on the stator windings of the totally enclosed and totally enclosed fan-cooled motors of table III were obtained with thermocouples which were well distributed in order to locate the hottest point. The testing procedure for the enclosed machines was carried beyond the requirements of the ASA standards, because some of the thermocouples were in locations that could not have been reached by inserting thermometers through holes in the frame. Consequently the recorded winding surface temperatures were approximately three degrees centigrade higher on the average than could have been obtained by the thermometer method.

The data on the open motors of table III were obtained by the thermometer method as defined in the present standards. In general, thermometers (or thermocouples)

Table III. Heating Data on Various Types of Induction Motors (See Appendix III)

Number Of Tests Averaged	Number of Motor Poles	Form of Mechanical Construction	Type of Motor	Temperature Measurements Taken on	‡Average Length of Test in Hours	Temperature Rise by Thermometer (or Thermocouple) Degrees Centigrade — Winding	Temperature Rise by Thermometer (or Thermocouple) Degrees Centigrade — Laminations	Temperature Rise of Hottest Surface by Thermometer (or Thermocouple)—Degrees Centigrade	Temperature Rise by Resistance Method—Degrees Centigrade	
17	2	#Fan cooled	Squirrel cage	Stator	5.5	47.9	32.6	47.9	47.2	
18	4	Fan cooled	Squirrel cage	Stator	6.0	51.5	35.3	51.5	50.2	
15	6	Fan cooled	Squirrel cage	Stator	6.0	45.2	33.2	45.2	44.2	
2	8	Fan cooled	Squirrel cage	Stator	7.4	52.5	36.0	52.5	49.5	
4	10	Fan cooled	Squirrel cage	Stator	6.7	45.5	34.8	45.5	45.0	
2	12	Fan cooled	Squirrel cage	Stator	6.0	46.5	33.0	46.5	45.5	
3		Fan cooled	Squirrel cage	Stator	1.0	44.0	31.7	44.0	43.0	
2		Fan cooled	Wound rotor	Stator	4.7	54.0	30.5	54.0	52.0	
2		Fan cooled	Wound rotor	Stator	1.0	39.0	28.0	39.0	37.0	
Total 65		Fan cooled		Stator		48.0	33.5	48.0	46.9† Average	
3	4	*Totally enclosed	Squirrel cage	Stator	8.8	51.7	*40.7	51.7	52.0	
3	6	Totally enclosed	Squirrel cage	Stator	7.8	41.3	*35.3	41.3	40.0	
2	8	Totally enclosed	Squirrel cage	Stator	9.2	52.5	*41.0	52.5	53.5	
2		Totally enclosed	Squirrel cage	Stator	0.5	36.5	*21.0	36.5	36.0	
16		Totally enclosed	Wound rotor	Stator	0.56	35.7	*23.1	35.7	36.8	
Total 26		Totally enclosed		Stator		39.5	27.8	39.5	40.1† Average	
6	2	Splashproof	Squirrel cage	Stator	3.3	27.3	32.3	32.5	27.8	
8	4	Splashproof	Squirrel cage	Stator	4.0	27.3	29.4	30.0	28.1	
7	6	Splashproof	Squirrel cage	Stator	3.4	25.6	28.9	29.6	27.1	
5	8	Splashproof	Squirrel cage	Stator	4.9	31.0	33.8	34.0	34.8	
5	10	Splashproof	Squirrel cage	Stator	3.1	19.0	21.4	21.4	19.6	
1	12	Splashproof	Squirrel cage	Stator	3.5	25.0	28.0	28.0	26.0	
5		Splashproof	Squirrel cage	Stator	0.5	28.2	32.0	32.0	30.2	
4		Splashproof	Wound rotor	Stator	5.4	36.0	38.3	38.8	39.5	
Total 41		Splashproof		Stator		27.4	30.5	30.8	29.0† Average	
25	2	Open	Squirrel cage	Stator	4.0	23.9	30.1	30.7	28.6	
14	4	Open	Squirrel cage	Stator	3.7	21.9	26.9	26.9	22.7	
8	6	Open	Squirrel cage	Stator	3.7	21.1	25.9	25.9	20.8	
12	8	Open	Squirrel cage	Stator	3.9	26.3	28.8	30.7	27.5	
8	10	Open	Squirrel cage	Stator	3.3	20.9	25.0	25.0	23.1	
3	12	Open	Squirrel cage	Stator	3.0	17.3	21.0	21.0	20.0	
2		Open	Squirrel cage	Stator	0.5	34.0	26.0	35.5	34.0	
18		Open	Wound rotor	Stator	4.0	26.3	30.3	30.2	30.4	
6		Open	Wound rotor	Stator	0.75	31.0	30.0	31.7	32.7	
Total 96		Open		Stator		24.3	28.4	29.0	26.9† Average	
16		*Totally enclosed	Wound rotor	Rotor	0.56	31.1	26.6	31.5	37.1	
4		Splashproof	Wound rotor	Rotor	5.4	32.8	27.3	34.0	38.0	
12		Open	Wound rotor	Rotor	4.0	24.0	23.1	25.2	28.9	
4		Open	Wound rotor	Rotor	0.75	28.8	23.7	28.8	33.0	
Total 36			Wound rotor	Rotor		28.7	25.2	29.4	34.0† Average	

264—Total number of tests.

Motors designated as fan-cooled are also totally enclosed.

* Motors designated as totally enclosed are not cooled by external fan. Stator lamination temperatures were measured on outside of frame on totally enclosed machines.

‡All tests longer than one hour (a total of 208) were taken on continuous rated motors. The remaining 56 tests of one hour or less were taken on motors with short-time ratings.

†Averages of temperatures are weighted in accordance with number of tests taken for each condition.

were distributed over laminations and winding at ten or more points. All surface measurements on wound rotors were made with thermometers after shutdown.

Most of the data on splashproof machines were actually taken with thermocouples, but similar maximum values of temperature rise by surface measurements could have been obtained with thermometers if a sufficient number of holes had been bored in the motor frames. It will be noted that on both splashproof and open machines, the average temperature rise of laminations exceeded that of the accessible parts of windings. Consequently the hottest part of many motors will not be reached if thermometers are placed on the windings only.

Maximum observed temperatures are tabulated (regardless of whether the maximum value occurred before or after shutdown). In each case a conscientious attempt was made to find the hottest observable spots on the machine. The average deceleration period was approximately one-half minute, from time load was removed until motor was stopped. Resistance measurements were obtained from one to two minutes after motor stopped. (These time intervals were slightly greater for large, high-speed machines.)

The heating tests tabulated in table III were not all made at the normal rated loads of the various motors. Tests on machines of similar constructions but with different ratings (such as 40 degrees centigrade, 50 degrees centigrade, etc.) are averaged together. Consequently the average values of temperature rise shown in this table are not a direct indication of the margin between actual tests and the conventional name-plate ratings for the different classes of motors.

Appendix IV. Comparison of 12 Open-Type Motors of Different Manufacturers

Identical testing methods were used to determine the comparative temperature rises of 12 different low-voltage four-pole, 60-cycle motors. Eleven of these machines were general-purpose open-type 25-horsepower motors rated 40 degrees centigrade rise, but one motor (designated as *K* in table IV) was rated 50 degrees centigrade because it had some protective features. Each motor was made by a

different manufacturer. Complete test results for continuous operation at rated load are given in table IV.

The lamination and conductor temperatures were obtained by surface measurements with either thermometers or thermocouples depending in each case on the accessibility of motor parts. However, when thermocouples were used, they were purposely placed in locations that could have been reached by thermometers if holes had been bored through intervening structural parts. Therefore the data in table IV were obtained in accordance with rules 2.055 and 2.063 of the present ASA standards. Only the maximum observed temperatures are recorded, but measurements were made at many different points on each machine. With the exception of motor *I*, the resistance method does not deviate from the maximum temperature rise observed by surface measurements by more than 3.5 degrees centigrade, and on eight of the motors the agreement is within 2 degrees centigrade.

The tests on these 12 motors were made successively by the same personnel, and the same dynamometer and metering equipment were used throughout. Therefore most of those controversial points were eliminated which usually arise when an attempt is made to compare heating characteristics of different motors. Since the motors represent a wide range of design proportions and ventilation arrangements, the consistency of the temperature data obtained by the resistance method is highly significant.

Five of the 12 motors had a maximum observable temperature rise by thermometer that was higher than the name-plate rating. These tests indicate that comparable results are not being obtained by different manufactures under the present standards—presumably because of differences in the extent of exploration with thermometers.

Table IV. Comparison of Open Motors of Different Manufacturers (Refer to Appendix IV)

Motor	Name Plate Rating—Degrees Centigrade	Test Values of Temperature Rise—Degrees Centigrade: Laminations	Conductors	Maximum Rise by Surface Measurement	By Resistance
A	40	41	38	41	41
B	40	42	34	42	41
C	40	34	37	37	37
D	40	28	31	31	27.5
E	40	24.5	25.5	25.5	23.5
F	40	34.5	28.5	34.5	32
G	40	33	32	33	34
H	40	44	37	44	45
I	40	47	34	47	41
J	40	32.5	30.5	32.5	30.5
**K*	50	59	61	61	62
L	40	29	24	29	27.5
Averages		37.4	34.4	38.1	36.8

* Motor *K* had some protective features.

Table V. Continuous Heat Runs for Various Loads and Voltages (See Appendix V and Figure 4)

(Motor Name-Plate Rating—Four Poles, 25 Horsepower, 220 Volts, Three Phase, 60 Cycles)

Voltage	Horsepower Load	Watts Input	Amperes	Total Motor Losses (Watts)	Temperature Rise—Degrees Centigrade: Winding Thermometer	Laminations Thermometer	Embedded Thermocouple	By Resistance
220	0	966	24.6	966	9	14	16	11
254	0	1,410	37	1,410	16	22	21	17
187	0	740	19.4	740	6	10	10	8
220	25.9	21,900	66.5	2,591	25	33	38	32
254	26.4	22,250	64.5	2,582	27	35	38	34
187	25.8	22,500	78.5	3,308	36	42	47	42
220	32.3	27,800	83	3,729	37	47	53	50
254	32	27,200	76	3,285	32	42	46	43
187	31.5	29,700	107	6,190	66	79	95	84
220	38.0	34,000	103	5,636	58	69	83	72
220	41.9	39,200	120	7,976	91	101	121	108

Appendix V. Temperature Measurements for Various Conditions of Motor Load and Voltage

An open-type 25-horsepower motor rated 220 volts at 1,800 rpm was selected for a series of 11 heat runs covering a wide range of conditions from zero to 168 per cent of normal load and from 85 to 115 per cent of rated voltage. Temperatures were measured by thermocouples which were inserted in internal parts of stator slots when the random winding was installed, by thermometers on windings and laminations, and by resistance method as tabulated in table V for continuous heat runs at each condition indicated. The laminations and windings were readily accessible, and thermometer readings were taken according to the ASA rules.

For operation at rated voltage, the resistance method indicated one degree centigrade to three degrees centigrade lower temperature than thermometers at normal load or less, but for extreme overloads the temperature is higher by resistance, the maximum difference being seven degrees centigrade at 168 per cent of rated load.

Thermocouples were distributed through the stator slots in order to locate the hottest internal point in the motor, and the maximum temperatures observed are designated as "embedded thermocouple" in table V and figure 4. In this random winding the embedded thermocouples are in close contact with the conductors, and are not separated from them by coil insulation as in the case where embedded-detectors are placed between two formed coils in the slot of a high-voltage motor. Therefore these embedded thermocouples indicate closely the theoretical "hottest spot" of the winding which was located at the middle of lamination stack. The "hottest spot" averaged five degrees centigrade higher than the temperature by resistance for the heat runs taken near normal load.

Figure 4 shows that the temperature rises by all methods are approximately proportional to the total motor losses. In general, increasing differentials are obtained between the temperature measurements by different methods as the motor losses are increased by overloading the machine.

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Discussion

For discussion, see page 472.

Measurement of Temperature in General-Purpose Squirrel-Cage Induction Motors

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FELLOW AIEE

THERE are three fundamental methods of temperature determination[1] which might be applied to squirrel-cage motors, namely:

1. The thermometer method
2. The resistance method
3. The embedded-detector method

It is the purpose of this paper to report results obtained by the three methods and to discuss the practical aspects of temperature measurement.

The standards of the American Standards Association,[2] AIEE,[3] and National Electrical Manufacturers Association[4] specify that the temperature rise of induction machines shall be determined by the thermometer method. Section 50 of the Test Code for Polyphase Induction Machines[5] is more general and reads as follows:

> Temperature tests are taken primarily to determine the amount of temperature rise on the different parts of the machine while running under a specified load. This rise in temperature is measured by either the rise in resistance of the current-carrying part, or by means of a thermometer, thermocouple, or embedded temperature detector. It is sometimes desirable to use one method as a check on the other.
>
> In measuring temperature rise by resistance, care must be taken to observe the precautions set forth in paragraphs 10 to 16 in order to secure accurate results, since a small error in measuring resistance may cause a comparatively large error in determining the temperature.
>
> The usual method of measuring temperature of open machines is by the use of alcohol or mercury thermometers or thermocouples, applied to the hottest part of the motor that is accessible. In the case of totally enclosed machines, due to the mechanical difficulties attending the use of alcohol or mercury thermometers, both during the run and after shutdown, thermocouples may be more convenient. . .

The test code specifies that thermometers or thermocouples shall be applied to the hottest part of the motor that is accessible. Definition 2.055 of the American Standards for Rotating Electrical Machinery[2] is more specific and reads as follows:

> *Thermometer Method of Temperature Determination Defined.* This method consists in the determination of the temperature, by mercury or alcohol thermometers, by resistance thermometers, or by thermocouples, any of these instruments being applied to the hottest part of the machine *accessible to mercury or alcohol thermometers.*

Thermometers Versus Thermocouples

It would seem that if proper precautions are observed in placing the instruments, the same results should be obtained with either thermometers or thermocouples. In order to check this assumption, several hundred temperature test records of squirrel-cage motors in sizes from 1 to 100 horsepower were examined. The temperature tests made before 1936 employed thermometers, and the results were checked by the resistance method. Tests made during the last two years employed thermocouples and the results were again checked by resistance measurements. It therefore seemed practical to obtain a comparison between thermometers and thermocouples by using the resistance measurements as a reference. The results of this comparison were disappointing. It was possible to arrive at the general conclusion that the temperature rise measured by thermocouple is higher than that measured by thermometer, but there was too much variation to justify establishing a differential which could be used for all conditions.

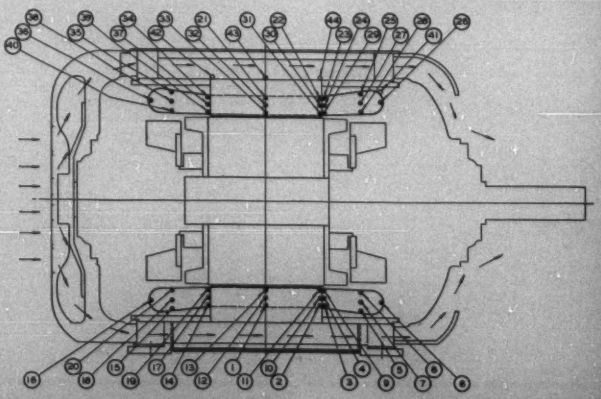
There are several explanations for the discrepancies. In the first place, the resistance measurements were only used as a check and it is likely that not enough emphasis was placed on the precautions which must be observed when using this method. The instruments were commercially accurate and readings were taken carefully, but there was probably not enough attention paid to the following paragraph (11) of the test code:[5]

> Every possible precaution should be taken to obtain the true temperature of the winding when measuring the cold resistance. The temperature of the surrounding air must not be regarded as the temperature of the windings unless the motor has been standing idle under constant temperature conditions for a considerable period of time.

It was also thought that some of the discrepancies in temperature tests might be due to inherent differences between thermometers and thermocouples.

Thermometers are calibrated while immersed in liquid to a specified depth, and it goes without saying that the liquid makes intimate contact with all parts of the bulb and part of the stem. Furthermore, thermometers are inflexible and

Figure 1. Location of thermocouples in totally enclosed fan-cooled motor



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1. For all numbered references, see list at end of paper.

due to their shape, can touch a plane surface, or most curved surfaces, at only two points. The question might therefore be raised whether a thermometer gives a true indication of the temperature of a winding, even when the bulb is covered with putty. On the other hand, a thermocouple is made of small, flexible wires and the junction can be put in a small opening and can be made to have intimate contact with a winding. Check tests made on cylindrical coils showed that thermocouples read higher than thermometers, the difference depending upon the curvature and smoothness of the coil surface, and the care used in making the application.

When a thermometer is used for measuring the temperature of a winding, at least a part of its stem is usually exposed to the cooling air and it was thought that this might affect the readings. This was checked by immersing a thermometer bulb in boiling water and directing the air from a desk fan on the entire stem. It was found that the reading was not affected as long as any appreciable amount of the bulb was immersed. With only the tip of the bulb in the water, the application of the fan reduced the reading three per cent.

In order further to investigate the subject, it was decided to build two 40-horsepower motors and to make careful temperature tests on these motors, by resistance, thermocouple, and thermometer, and to place enough thermocouples in the windings to locate surely, and measure the temperature of the hot spot. It was decided to build one motor of the totally enclosed fan-cooled type, and to test this motor with two rotors, one with heavy load losses and the other with relatively small load losses. It was decided to make the other motor an open-type machine and to test this motor with one rotor having small load losses.

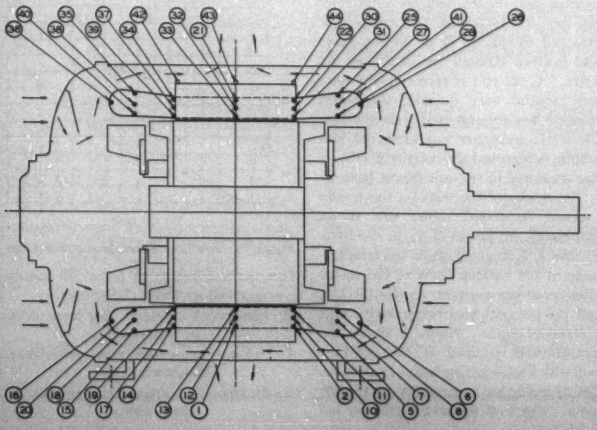

Figure 2. Location of thermocouples in open-type motor

Location of Hot Spot

Careful consideration was given to the location of the hot-spot thermocouples and useful information was obtained from a series of papers[6-11] presented at the midwinter convention of 1913. From these papers the conclusion was reached that the location and magnitude of the hot spot in the stator winding of a squirrel-cage motor depend upon its

1. Physical characteristics
2. Electrical and magnetic characteristics
3. Ventilation
4. Loading

A motor which is symmetrical about its vertical center line usually has a blower on each side and both free ends of the stator winding should be equally cooled. The parts of the coils which are embedded in the core are not so well ventilated and it seems likely that the highest coil temperature will be reached in the axial center of the core. If the design is unsymmetrical especially in case there is a blower on only one side of the motor, the free ends of the winding which are on the same side as the blower will be cooler than those on the opposite side, and the hot spot will probably shift away from the blower. The location of the hot spot vertically in the slot is not so easy to estimate, and will depend to a great extent on the direction of the heat flow between the winding and core. The direction of heat flow will depend on which member is producing the greater amount

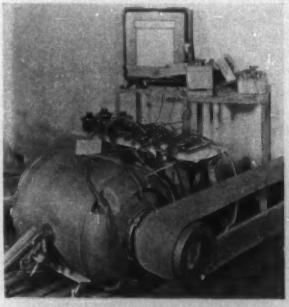

Figure 3. Equipment used for testing totally enclosed fan-cooled motor

of heat, which, for a given load, will vary with the electrical design, and for a given design will vary with the loading. With light loads the copper losses will be small and heat may flow from the core iron to the winding. At a certain heavier load there may be little interchange of heat between the core iron and the winding, and at still heavier loads, the heat may flow from the winding to the core. The winding near the mouth of the slot will not be as closely associated with the core iron as the rest of the winding, but on the other hand, will be subjected to the heat produced in the rotor, which, in a poorly designed motor, may be excessive.

In order to be reasonably sure of finding the hot spot, 44 thermocouples are installed in the totally enclosed fan-cooled motor as shown in figure 1. A thermometer extends through a slot in the end plate and the bulb of the thermometer is immediately adjacent to thermocouple number 41. There are 38 thermocouples in the open motor as shown in figure 2, and again the bulb of the thermometer is immediately adjacent to thermocouple number 41. Thermocouple number 41 and the thermometer bulb are on the outside of the tape which covers the free ends of the windings and are covered with a small amount of sealing compound. Thermocouples number 42, number 43, and number 44 are located on the stator iron and are also covered with a small amount of sealing compound.

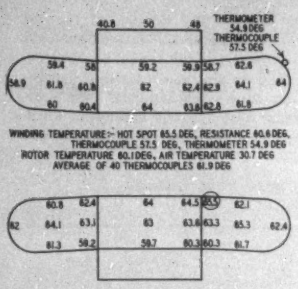
THERMOMETER 54.9 DEG
THERMOCOUPLE 57.5 DEG
WINDING TEMPERATURE:- HOT SPOT 65.5 DEG, RESISTANCE 60.6 DEG,
THERMOCOUPLE 57.5 DEG, THERMOMETER 54.9 DEG
ROTOR TEMPERATURE 60.1 DEG., AIR TEMPERATURE 30.7 DEG
AVERAGE OF 40 THERMOCOUPLES 61.9 DEG

Figure 4. Totally enclosed fan-cooled motor at 75 per cent full load

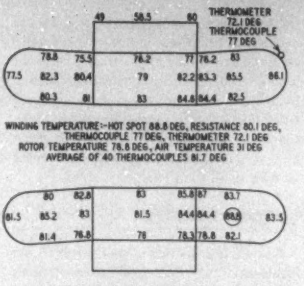
THERMOMETER 72.1 DEG
THERMOCOUPLE 77 DEG
WINDING TEMPERATURE:- HOT SPOT 88.8 DEG, RESISTANCE 80.1 DEG,
THERMOCOUPLE 77 DEG, THERMOMETER 72.1 DEG
ROTOR TEMPERATURE 78.8 DEG., AIR TEMPERATURE 31 DEG
AVERAGE OF 40 THERMOCOUPLES 81.7 DEG

Figure 5. Totally enclosed fan-cooled motor at full load

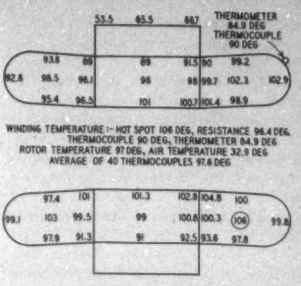
THERMOMETER 84.9 DEG
THERMOCOUPLE 90 DEG
WINDING TEMPERATURE:- HOT SPOT 106 DEG, RESISTANCE 96.4 DEG,
THERMOCOUPLE 90 DEG, THERMOMETER 84.9 DEG
ROTOR TEMPERATURE 97 DEG., AIR TEMPERATURE 32.9 DEG
AVERAGE OF 40 THERMOCOUPLES 97.8 DEG

Figure 6. Totally enclosed fan-cooled motor at 115 per cent full load

Thermocouples numbers 11, 13, 31 and 33 are silk taped to the top of a top coil side, next to the 0.025-inch insulation separating the winding from the one-eighth inch wooden wedge. Thermocouples numbers 10, 12, 30 and 32 are silk taped to the top of a bottom coil side, just below the 0.060-inch insulation separating the coil sides. Thermocouples numbers 1, 2, 21, and 22 are silk taped to the bottom of a bottom coil side, next to the 0.025-inch slot cell. (A top coil side is the one nearer the air gap; a bottom coil side is the one nearer the outside of the motor.) Thermocouples numbers 8, 9, 19, 20, 28, 29, 39, and 40 have radial positions corresponding to number 11, etc., thermocouples numbers, 4, 7, 17, 18, 24, 27, 37, and 38 have radial positions corresponding to number 4, etc., and thermocouples numbers 3, 5, 14, 15, 23, 25, 34, and 35 have radial positions corresponding to number 1, etc., but are on the free ends of the windings just inside the tape which covers the free ends. Thermocouples numbers 6, 16, 26, and 36 are silk taped to the loops of the coils, just inside the tape. Figures 1 and 2 are drawn approximately to scale and show the relative dimensions of the various parts as well as the location of the thermocouples. Both stators are wound to the same specification, of double-cotton-covered wire, with double-layer diamond windings in semienclosed slots. The stators have only one dipped and baked coat of varnish, additional coats having been omitted to save time. There are no ventilating ducts in either the stator or rotor and no openings through the rotor. The squirrel cages are of cast aluminum construction.

Apparatus and Test Results

The arrangement of the apparatus is shown in figure 3. The thermocouple leads are enclosed in spaghetti tubing

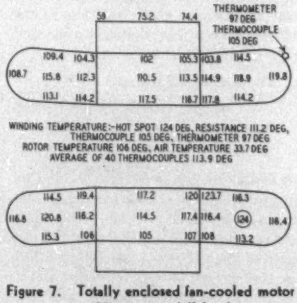
THERMOMETER 97 DEG
THERMOCOUPLE 105 DEG
WINDING TEMPERATURE:- HOT SPOT 124 DEG, RESISTANCE 111.2 DEG,
THERMOCOUPLE 105 DEG, THERMOMETER 97 DEG
ROTOR TEMPERATURE 106 DEG., AIR TEMPERATURE 33.7 DEG
AVERAGE OF 40 THERMOCOUPLES 113.9 DEG

Figure 7. Totally enclosed fan-cooled motor at 125 per cent full load

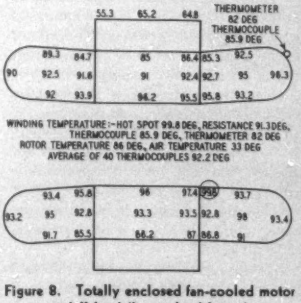
THERMOMETER 82 DEG
THERMOCOUPLE 85.9 DEG
WINDING TEMPERATURE:- HOT SPOT 99.8 DEG, RESISTANCE 91.3 DEG,
THERMOCOUPLE 85.9 DEG, THERMOMETER 82 DEG
ROTOR TEMPERATURE 86 DEG., AIR TEMPERATURE 33 DEG
AVERAGE OF 40 THERMOCOUPLES 92.2 DEG

Figure 8. Totally enclosed fan-cooled motor at full load (heavy load losses)

and are divided into four groups and brought out of the motor through the air-gap plug holes. The leads are connected to terminal boards and may be connected either to an indicating or recording instrument by means of dial switches. A double bridge was used to measure the resistance of the stator winding, and the temperature of the rotor was measured by means of a thermocouple attached to the tip of an air-gap gauge and inserted through one of the air-gap holes. At the end of each run, the rotor was stopped very quickly, the stator winding was disconnected from the line, the stator resistance was measured in a minute or less, and the rotor temperature was measured in two minutes or less.

The results of the tests on the totally enclosed fan-cooled motor are shown graphically in figures 4 to 9, inclusive. Figures 4, 5, 6, and 7 show the temperatures in the various parts of the motor after becoming constant, at 75, 100, 115, and 125 per cent load respectively, with a standard rotor. Figure 8 shows the temperatures attained at 100 per cent load with a rotor having heavy load losses. The figures in the large circles are the hot spots. Figure 9 shows the relation between hot-spot temperatures and temperatures by resistance, thermocouples, and thermometers for the various tests illustrated in figures 4, 5, 6, and 7. It is believed that the diagrams and curves

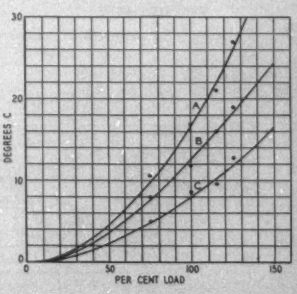

Figure 9. Totally enclosed fan-cooled motor

Forty horsepower, three phase, 60 cycles, 220/440 volts, 1,750 rpm

A—Hot-spot temperature minus temperature by thermometer

B—Hot-spot temperature minus temperature by thermocouple

C—Hot-spot temperature minus temperature by resistance

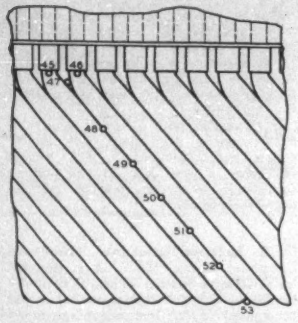

Figure 10. Temperature in coil extension of open-type 40-horsepower motor at full load

Nine Thermocouples

Number	45	46	47	48	49	50	51	52	53
Deg C	46.6	44.3	44.3	53.0	53.1	54.1	54.1	42.8	44.1

are self-explanatory, and the test results seem to be consistent with each other. It should be noted that the cooling fan is on the left side and the hot spot is on the right side of the fan-cooled motors. One point of particular interest is the close agreement between the average of the temperatures obtained from thermocouples numbers 1–40, inclusive, and the temperature by resistance, indicating that the thermocouples are located judiciously, and that the readings are accurate.

Similar tests were made on the 40-horsepower open-type motor and the results were not what had been anticipated. The open-type motor is supposedly symmetrical about both center lines and it is reasonable to expect that the temperatures of corresponding parts would be identical. However, the coil extensions on the pulley end are considerably hotter than on the opposite end. An examination of the motor showed that the windings are not symmetrical but are considerably shorter on the pulley end, which probably accounts for the difference in temperature. The readings of the thermometer and thermocouple number 41 were much lower than expected and very much lower than the temperature by resistance and hot-spot temperature. This made it seem probable that they were not located in the right place and the motor was inspected with this idea in mind. It was found that the thermometer was inserted through a hole drilled in the frame with the thermocouple immediately adjacent to the thermometer bulb, and while the location of the thermometer was not ideal, it did not seem to be far away from the proper location. In order to find the hottest external part of the coil extension, nine more thermocouples were placed on the surface of the winding as shown in figure 10. It will be noted that thermocouples number 50 and 51 give results about ten degrees higher than number 52 and 53. Temperature tests were then made at 100 per cent, 125 per cent, 144 per cent, and 160 per cent of full load using thermocouple number 51 and a thermometer whose bulb is immediately over this thermocouple. The results of these tests are shown graphically in figures 11 to 15 inclusive and are self-explanatory. The averages of thermocouples number 1–40 inclusive do not check the temperature by resistance, but fair agreement is obtained by eliminating numbers 6, 8, 16, 20, 26, 28, 36, and 40, which are located directly in the path of the cooling air. Figure 15 shows the relation between hot-spot temperatures and temperatures by resistance, thermocouples, and thermometers for the various tests illustrated in figures 11–14 inclusive.

Conclusions

A revision of the standards which specify the method of measuring the temperature rise of induction machines is desirable and should be undertaken. The determination of temperature rise should not depend on surface measurements taken either by thermometer or thermocouple, because it is often difficult, and sometimes impossible to locate these instruments properly. Even though a machine is so constructed that there is no interference with the installation of thermometers, it is not good practice to leave the location of thermometers to the judgment of even the most careful and conscientious testers, because they ordinarily have no way of determining the hottest accessible spot. Elimination of thermometers and thermocouples will leave only the resistance method for machines of ordinary size and voltage, and while this method requires skillful technique on the part of the tester, it has been used in transformer heat runs for many years and is strictly a commercial method.

If the resistance method is adopted, it will be necessary to revise the conventional allowances[1] for hot spot and to increase the standard temperature ratings for induction machines about five degrees

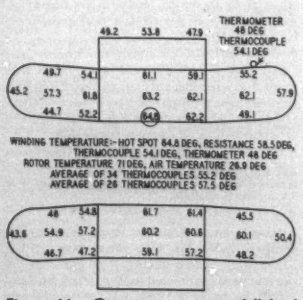
THERMOMETER 48 DEG
THERMOCOUPLE 54.1 DEG
WINDING TEMPERATURE:- HOT SPOT 84.8 DEG, RESISTANCE 58.5 DEG,
THERMOCOUPLE 54.1 DEG, THERMOMETER 48 DEG
ROTOR TEMPERATURE 71 DEG, AIR TEMPERATURE 26.9 DEG
AVERAGE OF 34 THERMOCOUPLES 55.2 DEG
AVERAGE OF 26 THERMOCOUPLES 57.5 DEG

Figure 11. Open-type motor at full load

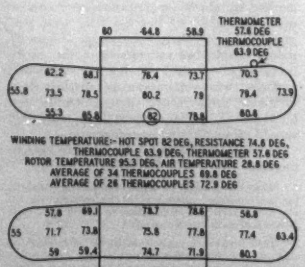
THERMOMETER 57.6 DEG
THERMOCOUPLE 63.9 DEG
WINDING TEMPERATURE:- HOT SPOT 82 DEG, RESISTANCE 74.8 DEG,
THERMOCOUPLE 63.9 DEG, THERMOMETER 57.6 DEG
ROTOR TEMPERATURE 95.3 DEG, AIR TEMPERATURE 28.8 DEG
AVERAGE OF 34 THERMOCOUPLES 69.8 DEG
AVERAGE OF 26 THERMOCOUPLES 72.9 DEG

Figure 12. Open-type motor at 125 per cent full load

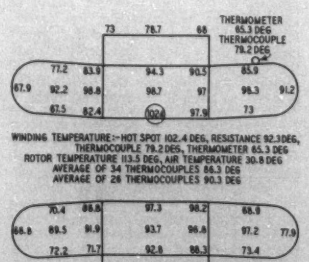
THERMOMETER 65.3 DEG
THERMOCOUPLE 78.2 DEG
WINDING TEMPERATURE:- HOT SPOT 102.4 DEG, RESISTANCE 92.3 DEG,
THERMOCOUPLE 78.2 DEG, THERMOMETER 65.3 DEG
ROTOR TEMPERATURE 113.5 DEG, AIR TEMPERATURE 30.8 DEG
AVERAGE OF 34 THERMOCOUPLES 86.3 DEG
AVERAGE OF 26 THERMOCOUPLES 90.3 DEG

Figure 13. Open-type motor at 144 per cent full load

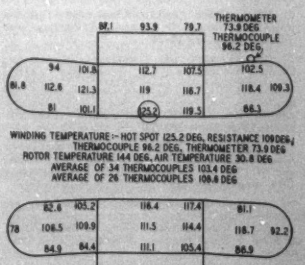
THERMOMETER 73.9 DEG
THERMOCOUPLE 96.2 DEG
WINDING TEMPERATURE:- HOT SPOT 125.2 DEG, RESISTANCE 109 DEG,
THERMOCOUPLE 96.2 DEG, THERMOMETER 73.9 DEG
ROTOR TEMPERATURE 144 DEG, AIR TEMPERATURE 30.8 DEG
AVERAGE OF 34 THERMOCOUPLES 103.4 DEG
AVERAGE OF 26 THERMOCOUPLES 108.8 DEG

Figure 14. Open-type motor at 160 per cent full load

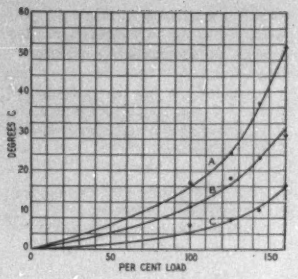

Figure 15. Open-type motor

Forty-horsepower, three phase, 60 cycles, 220/440 volts, 1,750 rpm

A—Hot-spot temperature minus temperature by thermometer

B—Hot-spot temperature minus temperature by thermocouple

C—Hot-spot temperature minus temperature by resistance

centigrade. Such an increase would result in the following ratings:

Open-type continuous ratings 45 degrees centigrade

Protected and intermittent ratings 55 degrees centigrade

Totally enclosed continuous ratings 60 degrees centigrade

References

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2. American Standards for Rotating Electrical Machinery, ASA C50-1936, approved January 6, 1936, pages 23–7.

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4. NEMA Motor and Generator Standards, publication number 38–49, May 1938, page 35, note III; page 51, note II; page 58, note II.

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6. High Speed Turboalternators—Designs and Limitations, B. G. Lamme. AIEE Transactions, 1913, pages 19–25.

7. Temperature and Electrical Insulation, C. P. Steinmetz and B. G. Lamme. AIEE Transactions, 1913, pages 83–9.

8. Notes on Internal Heating of Stator Coils, R. B. Williamson. AIEE Transactions, 1913, pages 153–62.

9. Measurement of Temperature in Rotating Electric Machines, L. W. Chubb, E. I. Chute, and O. W. A. Oelting. AIEE Transactions, 1913, pages 163–75.

10. Method of Determining Temperature of Alternating Current Generators and Motors and Room Temperature, Henry G. Reist and T. S. Eden. AIEE Transactions, 1913, pages 177–84.

11. Thermocouples and Resistance Coils for the Determination of Local Temperatures in Electrical Machines, J. A. Capp and L. T. Robinson. AIEE Transactions, 1913, pages 185–90.

Discussion

P. H. Rutherford (General Motors Corporation, Dayton, Ohio): The results shown in the paper by C. P. Potter agree very well with the results of similar tests carried out on small single-phase motors. Extensive tests carried out on a one-horsepower single-phase motor showed that the hot spot occurred in the center of the end turns of the winding and did not appear to shift with variations in load. This hot-spot temperature was approximately ten per cent greater than the temperature rise by resistance, a result which checks quite well with data obtained from much larger motors. If the resistance method proves satisfactory, it might be well to consider the allowances for hot spot as a per cent of the temperature rise by resistance rather than a constant allowance of about 5 degrees centigrade. This would serve to extend temperature standards to motors of ratings higher than 60 degrees centigrade in case such designs should prove desirable in the future.

It would have been interesting to consider the curves in this paper plotted against motor losses as well as per cent of full load. Since one motor was tested with a standard rotor and a rotor with heavy load losses, it would seem that for the same losses the temperature rise and possibly the hot-spot temperatures would agree quite well. A comparison of the temperature versus losses curves for the open and the totally enclosed type motors would also be very interesting.

P. L. Alger (General Electric Company, Schenectady, N. Y.): The discussion has brought out a possible difficulty in obtaining the correct temperature rise of a motor by the resistance method, due to the time delay between the instant of shutdown and the time the measurement is taken. This same problem occurs in other types of apparatus, for which the resistance method of measurement is generally used. I should, therefore, like to call attention to paragraph 10.292 of appendix I of the proposed ASA standards for transformers, which gives a simplified method of determining this correction by calculation. This method is to apply an empirical correction to the degrees centigrade as measured by the resistance method. The correction is equal to the product of the watts loss per pound of copper in the winding under test (determined by the current density in the copper) multiplied by a factor that depends upon the time elapsed between the instant of shutdown and the time the measurement is taken, as given in the following table:

Time in Minutes	Factor
1	0.19
1½	0.26
2	0.32
3	0.43
4	0.50

The factors given in this table apply to oil-insulated windings, and are representative of the normal rate of heat flow from the copper into the oil. It seems clear, however, that similar factors can be derived for motor windings or other apparatus, that would be quite accurate enough for test purposes, in view of the small magnitude of the correction.

For example, with a current density of 3,000 amperes per square inch in the copper, and a temperature of 75 degrees centigrade, a time delay of two minutes corresponds to a correction of only 2.4 degrees centigrade.

G. R. Anderson (Fairbanks, Morse and Company, Beloit, Wis.): Any proposal for revision of existing standards naturally brings out data and experience that should be utilized to the best advantage in its consideration.

The various papers presented have outlined fully the many factors that must be considered, the variations to be expected, and the weight to be given to each.

Referring to the recommendations in C. P. Potter's paper, the writer has taken the opportunity of making an analysis of approximately 100 tests on various sizes of enclosed fan-cooled motors ranging from 1 to 100 horsepower. The list selected contained only ratings designed for general-purpose application. Those with special characteristics or having large rotor load losses were eliminated. Each motor had been tested for shutdown winding temperatures by thermometer and by resistance. Averaging these tests gave the following:

Average increase of temperature rise by resistance measurement over thermometer measurement was 6.9 degrees centigrade.

Average increase in percentage was 19.2.

Another analysis of the same tests was made by selecting only 40 ratings that had temperature rise by either resistance or thermometer between the range of 40 degrees centigrade and 60 degrees centigrade. The averages of this group gave the following:

Average increase of temperature rise by resistance measurement over thermometer measurement was 8.2 degrees centigrade.

Average increase in percentage was 17.4.

It will be noted that these percentages compare favorably with those recorded by Mr. Potter, which averaged 22 per cent on the enclosed fan-cooled motor tested by him.

On the basis of these data it would appear reasonable to recommend that where present standards by thermometer measurement are now 40 degrees rise, that permissible equivalent resistance measurements should fall somewhere in the neighborhood of 47 and 48 degrees centigrade, and that where maximum permissible thermometer temperature measurements are 55 degrees centigrade, the resistance method should allow 65 degrees centigrade.

In addition to the above it is recommended

1. That the present 40-degree-centigrade standard by thermometer measurement be retained for all machines having modifications to which this type of measurement can be applied.

2. That resistance measurement be permitted for enclosed machines and those having mechanical modifications which make the application of thermometers impractical.

3. That the resistance measurement be the only method adopted as standard for field-coil temperature measurement.

C. G. Veinott (Westinghouse Electric and Manufacturing Company, Lima, Ohio): In the course of the application of thermal protective devices the writer had occasion to take numerous temperature runs on a line of fractional-horsepower motors at high degrees of overload, causing high temperature rises. Temperatures were measured by a thermometer placed on the "hottest accessible" part of the end winding, by a thermocouple installed on the end winding (*not an embedded detector*), and by rise of resistance. The results are tabulated in table I of this discussion.

Table I

Horsepower Rating	Per Cent Load	Open or Enclosed	Shutdown Temperature Rises by: Thermometer	Thermocouple	Resistance
1/4	200	Open	61	83	77.5
1/4	160	Enclosed	76	89	79.2
1/4	190	Open	66	82	83.3
1/4	140	Enclosed	78	88.5	83.5
1/2	180	Open	66	86	85.4
1/2	130	Enclosed	70.5	89	74.5
1/2	180	Open	58.5	79.5	71.5
1/2	130	Enclosed	75.8	84.8	82.7
1/4	160	Open	87	100	100
3/4	130	Enclosed	89	97	81.5

As a result of these and other tests, the writer draws the following conclusions as applying to fractional-horsepower motors:

1. Thermocouples should be recognized form of temperature measurement. It is frequently the practice of builders of motor-driven appliances to run application tests on their machines. In many cases, thermocouples are practically the only way of measuring the temperatures attained by the windings because the motor itself is not readily accessible and sometimes control circuits are so interlocked that it is not easy or even possible to measure the rise by resistance. Refrigeration and air-conditioning appliance manufacturers necessarily use thermocouples for the temperature measurements made to determine the thermodynamic performance of the whole apparatus; thus thermocouples afford the simplest and easiest means for measuring the motor temperature.

2. The limiting temperatures, when measured by a thermocouple installed on the "hottest accessible spot of the windings," should be the same as the limiting temperatures for the rise-of-resistance method, instead of the same as by thermometer as now. This recommendation is conservative because the thermocouple temperatures are generally higher than those obtained by rise of resistance.

3. The rise-of-resistance method is not reliable for measuring the temperature of an auxiliary winding if there is a starting switch in the circuit because of variations in contact resistance. Very serious errors have been observed because of switch contact resistance.

4. In view of the fact that, with thermal overload devices, some very high temperature rises are often measured, it might be better to express the correction for the different methods of temperature rise as a per cent of the measured rise, instead of using a flat correction in degrees as now. Potter's figures 9 and 15 support this conclusion.

A. S. Hill (University of Maine, Orono): My experience with the thermometer method in research work on fully enclosed fan-cooled induction motors supports Mr. Summers' conclusion that reliable winding temperature data cannot in general be obtained on such machines by inserting thermometers through holes in frames or covers at the close of heat runs in accordance with ASA rule 2.063. In my first series of experiments on motor ventilation, back in 1932, an attempt was made to determine ultimate insulation temperatures in this way; but, despite the fact that the thermometers were always applied by the same personnel under conditions presumably more conducive to accuracy than those usually encountered in field tests, results were so inconsistent that the procedure was soon abandoned in favor of resistance measurements.

The impossibility of properly covering bulbs with pads or putty when, on shutdown, thermometers must be quickly applied through small openings, is in itself a sufficient justification for a revision of the standards relating to temperature measurements on partially enclosed and totally enclosed machines. Thermometer observations of stator core temperatures, in the fan-cooled motor investigation just mentioned, indicate that even when the bulbs are immersed in oil in small wells drilled in the core structure to receive them, and are as a consequence afforded a fairly close contact with the laminations, and almost complete protection from the influence of air streams, the readings are likely to be from four to eight degrees too low unless the annular openings around the stems at the top of the bulbs are completely closed with cones of putty. In commercial testing under existing standards, where thermometers have to be pushed in through holes at the conclusion of a run, the "point contact," justly criticized by Mr. Summers, is about all that can be expected; and, although at standstill the bulbs are not subject to cooling by forced convection, the large percentage of bulb area exposed to the surrounding air is certain to have a marked but indeterminable effect in lowering the reading. Such observations, though possibly of interest in comparing the performance of different designs, are obviously inadequate as a basis for rating machinery.

Both Mr. Potter and Mr. Summers very properly emphasize the great importance of an accurate determination of the winding temperature corresponding to "cold resistance." This correlation is unquestionably the most vital step in the successful application of the resistance method as a means of securing dependable heating data on machinery insulation, particularly in the case of motors of the enclosed type. For as the extent of enclosure is increased, not only are the windings less accessible to thermometers, but much more sluggish in cooling after load tests or in following changes in ambient temperature. With a completely closed structure many hours may elapse after any thermal disturbance before the copper reaches the exact temperature of parts, such as laminations, bearing brackets, or shields, to which thermometers can be conveniently applied. In an endeavor to attain an accuracy well within one degree in the evaluation of average winding temperatures, I have found it necessary to remove both end covers of the motor enclosure, place thermometers on the insulation and adjacent laminations, and, taking readings at regular intervals, defer the "cold resistance" measurement until a state of complete thermal equilibrium with the ambient was observed. While such a degree of disassembling would doubtless be inconvenient in factory testing, and ordinarily impracticable in the field, its desirability in an engineering investigation shows that the code requirements quoted by Mr. Potter and the precautions urged by Mr. Summers are extremely important and none too severe.

In an extended research where, after due investigation, thermometers can be strategically and permanently placed with bulbs properly protected from the influence of surrounding air, the temperatures which they indicate may be fully as consistent as those determined by any other means; but when hurriedly applied after shutdown, with insufficient contact area, inadequate bulb protection, and no certainty as to correct location, the accuracy of the resulting hottest-spot temperature cannot compare with that attainable by resistance measurements. Moreover, in loading-back tests, the resistance method offers the possibility of checking winding temperature at any time during the run by the momentary removal of a-c power to permit bridge observations, the machine being driven by its loading generator during this interval. Whether or not resistance values obtained under these conditions would be acceptable as a criterion of ultimate insulation temperature at the end of test, is open to question; but, in some instances at least, I have found them to yield results apparently more dependable than those of readings taken after the machine was shut down.

L. A. Kilgore (Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa.): In the measurement of temperature by resistance, there is an additional difficulty not mentioned by C. P. Potter and E. R. Summers. This difficulty arises from the fact that the temperature of a winding changes very rapidly in the first few minutes after shutdown and the reading at one minute after shutdown may be about two to six degrees lower than the actual average temperature; furthermore, if one tester gets the readings in 1/2 minute and another in 1 1/2 minutes, the readings may differ by about this same amount.

There is an accurate method of overcoming this difficulty which the writer believes should be incorporated as part of any proposed standard test by resistance, to be used whenever the readings cannot be taken within one-half minute. This method consists of plotting the curve of temperature (or resistance) against time and projecting back to the instant of shutdown. The initial slope of this time-temperature curve can be shown to be the initial average loss per unit of conducting material divided by the thermal capacity. Thus, in copper (neglecting eddy currents and using constants for copper at 75 degrees), the initial rate of change in degrees centigrade per minute is equal to 0.9 times (current density in thousands of amperes per square inch).[1]

With tests made in this more accurate manner (projecting back to the instant of dumping load), our general experience on open motors above 200 horsepower has been that 10 to 15 degrees differential exists between temperature by resistance and by thermometer. For totally enclosed motors, this differential is somewhat less, depending on how the machine is ventilated

and how hard it is worked, but tests on a number of motors indicate a five- to ten-degree differential.

It may be desirable to use temperature by resistance for enclosed machines and other inaccessible machines, but before this can be made standard, an agreement must be reached on the exact method of test and on the proper differential between resistance and thermometer temperature limits.

Henry Thomas (Sun Oil Company, Philadelphia, Pa.): The papers by Mr. Summers and Mr. Potter have covered the subject so well and presented data and logical discussions in such a complete form, that there is little to be added. The points are brought out so clearly showing the weakness of the existing methods of temperature determination and the advantages and the reasonableness of the resistance method, that there seems no answer except to adopt it as the only consistent, accurate, and convenient method to be used for all types of motors, but especially that of the enclosed, or partially enclosed type.

The authors have brought out very clearly that the thermometer method at best gives quite variable results, cannot be checked by any two persons, even those experienced, and that with a very large number of present-day motors it is impossible, or practically so, to use thermometers.

I have very strongly favored the use of the resistance method for use on induction motors since 1930 and this method has been specified on all equipment purchased by the company that I represent since that time. A great many tests have been made on motors of practically all sizes and types and from various manufacturers which have fully convinced me that this method is first of all, far more consistent, is easily made, and can readily be used in the shop or in the field. When the preliminary report on the test code for induction motors was first brought out, I wrote to the chairman of that committee regarding this matter, and recommended its adoption as the standard method, but allowing the use of thermometers either for special purposes, or as a check.

I am in agreement with most of the conclusions drawn from the data and reasoning presented in the papers. These conclusions and recommendations, if carried out, will prove a distinct advance in the accurate and consistent temperature rating of induction motors.

With reference to one of the proposals, however, I have been able to find very little justification for placing the new limits of temperature rise as measured by resistance five degrees centigrade above the present limit determined by thermometer. Our own careful observation over a period of eight to ten years indicates that the temperature rise of induction motors of the usual commercial types will agree very closely when taken by the resistance method and by thermometer, provided the thermometer is used with proper care as to selection of location on the winding and proper placing and protection of the thermometer bulb, or if a thermocouple is used and placed with the same consideration.

An analysis of the data presented in Mr. Summers' paper will, I believe, bear this out to a very large degree, for example in table III.

Average temperature rise, fan-cooled motors—46.9 degrees centigrade by resistance, 48.0 degrees centigrade by thermometer

Average temperature rise, enclosed (no fan) motors—40.1 degrees centigrade by resistance, 39.5 degrees centigrade by thermometer

Average temperature rise, splashproof motors—29.0 degrees centigrade by resistance, 30.8 degrees centigrade by thermometer

Average temperature rise, open motor—26.9 degrees centigrade by resistance, 29.0 degrees centigrade by thermometer

Our own tests on motors of various makes of the above types bear out these results very closely in every respect. If comparison is made of the thermometer against the resistance method, when thermometers are placed on practically any location on coils and without proper covering of the bulbs, either because of indifference or because of lack of accessibility of the parts, then the difference of the two methods may be 5 degrees centigrade or much more, up to 15 degrees centigrade or 20 degrees centigrade, as pointed out in the paper.

Mr. Summers states: "The resistance method gives results that are essentially the equivalent of careful exploration by thermometer." It should be remembered that the present method considers the rise as that of the hottest point on the winding, iron, or active parts of the motor, which can be read by thermometer, so it is only logical in making comparisons that readings as taken by the resistance method should be compared with the thermometer method when it is done in all its details with proper care. I believe it is quite evident, even with open motors, that it is more difficult and requires more time to take a sufficient number of thermometer readings to get the highest accessible temperature, than to take the reading by the resistance method. In the case of the enclosed motor, as indicated in the paper, the resistance method is the only practical one.

I do not believe any term such as "conventional allowance" should be considered in adopting a new method of rating, whether it refers to five degrees, ten degrees, or any other amount. A change to the resistance method would place the determination of temperature on an accurate basis with all data readily determinable, and easily checked.

The present standard of temperature rise, especially for closed motors, is already high and should not be changed because the resistance method is used. The resistance method is an average indication and does not indicate what is the so-called "hot spot" condition. The temperature which can be obtained by the thermometer method, if sufficient care is used, may be as high or even higher than by resistance, since it takes in all active parts as well as the windings. For this reason I feel that the present temperature rise should be maintained.

R. J. Sullivan (The Commonwealth and Southern Corporation, Jackson, Mich.): The adoption of motor temperature rise determination by resistance as the standard method, as proposed in these papers, is a step which is long overdue in the motor manufacturing industry. Manufacturers have been measuring temperature rise by resistance for years as a check on thermometer measurments, but the results obtained with the thermometers have largely been relied upon in rating motors and making test reports, due to the fact that this method has been specified as standard.

The writer, having been responsible for motor design and testing in several organizations, and being now associated with an organization which applies many motors, has long believed that motor temperature rise obtained by the resistance method is simpler, more consistent, and more accurate than that obtained by the thermometer method, and that the resistance method should be adopted as the standard method. Mr. Summers and Mr. Potter have made a valuable contribution to the industry by providing quantitative proof to support their recommendations.

When the resistance method is used with the proper equipment and precautions, persons not associated with the tests can rely on the reported results or check them, without the uncertainty which accompanies results obtained by thermometer measurements in regard to the location and method of application of the thermometers, presence of drafts, thermometer preheating and time of application after shutdown, and other factors.

An organization which purchases motors in any considerable quantity can better afford to invest in the necessary equipment for accurate resistance measurements than to maintain skilled test personnel for the intelligent application of thermometers in heat runs. The resistance method is a much more convenient and consistent method for the motor consumer to use, especially in the case of enclosed or built-in motors, and it would be of considerable value to have these tests consistent with the methods used by the motor manufacturers as a basis for ratings, guarantees, and test reports.

The precautions emphasized in the papers in regard to taking "cold resistance" are important and should not be overlooked by anyone checking motor temperature rise by the resistance method. A motor may be brought in for test from an unheated storeroom where the ambient temperature is 20 degrees centigrade or 25 degrees centigrade less than that of the test room, or a field test may be made before a machine has thoroughly cooled after previous operation in service. The resistance changes approximately one per cent for each $2^1/_2$-degree-centigrade difference in temperature.

R. E. Hellmund (Westinghouse Electric and Manufacturing Company, East Pittsburg, Pa.): The paper by Mr. Summers recommends a change from the thermometer to the resistance method of measuring temperature-rise in our various commercial standards (see also reference 7 of the paper). There is no question as to the desirability of making this change for some types of machines, but it is doubtful that a wholesale change, including large machinery, is justified at this time. Whenever and wherever the change is made, a question immediately arises as to the value which should be used for the permissible temperature-rise by resistance. The natural inclination is to establish this value by taking

Table II

	A	B	C	D
Allowable hot-spot temperature (degrees)	105	105	105	105
Allowance for ambient (degrees)	40	25	30	30
Allowance for difference between hot-spot and resistance measurement (degrees)	12	5	6	10
Per cent	(22.5)	(6.5)	(9)	(15)
Temperature rise by resistance (degrees)	53	75	69	65
Allowance for load factor (degrees)	10	0	3	0
Per cent	(23)	0	(4.5)	0
Temperature rise allowing for load factor (resistance) (degrees)	43	75	66	65
Allowance for variations in power supply (degrees)	6	3	3	5
Per cent	(16)	(4)	(5)	(8.5)
Temperature rise allowing for load factor and variations in power supply (resistance) (degrees)	37	72	63	60
Allowance for service mounting (degrees)	7	2	3	0
Per cent	(23.5)	(3)	(5)	0
Temperature rise allowing for load factor, variations in power supply, and service mounting (resistance) (degrees)	30	70	60	60
Allowance for difference between resistance and thermometer (degrees)	6	4	8	10
Per cent	(25)	(6.5)	(16.5)	(20)
Temperature rise allowing for load factor, variations in power supply, and service mounting (thermometer) (degrees)	24	66	52	50

into account the difference between the values by thermometer and by resistance determined by tests such as described in the paper. Data of this nature undoubtedly are of value and should receive due consideration; however, it should be determined whether a better method might not be to work down from the more basic value allowed for the hot-spot temperature to a permissible value by resistance. In so doing, it will not be practicable to make allowance for each of the various factors independently, but the whole problem should be considered broadly and a decision reached regarding the best philosophy of rating.

In rating and applying electric motors, a great many factors have to be given consideration, such as the permissible hot-spot value, ambient temperature, the difference between the hot-spot and resistance measurements, variations in power supply (particularly voltage), service difficulties resulting from insufficient knowledge of the expected load, differences in cooling between the test-floor and service mounting, etc. All of these factors are not merely theoretical possibilities, but can be of appreciable importance either individually or collectively. In table II of this discussion an attempt has been made under *A* to take all of these factors into account. The differences between temperatures are given in degrees and also in percentages, the latter in most cases being the best figure for evaluation. The allowances for all values under *A* are not the maximum experienced for each particular factor indicated but are values approximating the safer limit. It will be noted that this method results in a temperature-rise of 30 degrees by resistance and of 24 degrees by thermometer. Obviously, nobody would consider the adoption of these values as rating standards in view of the extensive experience available showing satisfactory all-round results with the present 40- and 50-degree ratings (by thermometer). This is simply an admission of the fact that we cannot afford to adopt methods too conservative, because it would result in an enormous economic waste.

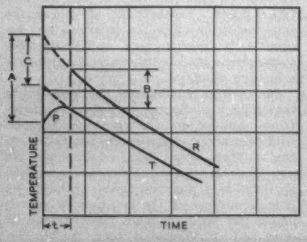

Figure 1. Cooling curves

Under *B*, values have been introduced approximating the average values found in practice. Zero has been given for the load factor because the actual load will be below at least as frequently as above the estimated load values. This leads to values of 70 degrees rise by resistance and 66 degrees by thermometer. It is again evident that nobody will seriously consider this practice, because experience with 40- and 50-degree ratings (by thermometer) do not indicate that the appreciably higher values given under *B* can be used safely. Under *C*, certain intermediate values have been selected more or less arbitrarily, resulting in a value of 60 degrees by resistance. There is no particular merit in the values given under *C* except that they lead to 60 degrees, which is the international value and one which also is now used in a number of our American standards. All of these figures indicate that the tendency which has developed to allow in the rating structure for all sorts of possibilities is impracticable.

We should, therefore, realize that in rating and applying machines there are three responsible parties involved—namely, the manufacturer, the central station, and the user—and that no one of them can be held responsible for factors which are beyond their knowledge or control. This naturally leads to a method of establishing satisfactory values for a rating structure such as shown under *D*. Here the equivalent ambient temperature has been assumed to be 30 degrees, a value which will cover the majority of all applications; a rather liberal allowance has been made for the difference between the hot-spot and resistance measurement values, and a moderate allowance has been made for the frequently occurring smaller variations in the power supply. The value arrived at for the resistance method is 60 degrees. With this as a background, the user knows that the machine which he buys will be suitable for the majority of reasonably normal conditions met in practice. On the other hand, if he feels that in his application he is likely to encounter exceptionally high ambient temperatures or that his power supply differs considerably from the rated value of the motor, or, again, if he is uncertain about his load or is not sure that he is applying the motor without interfering with the normal cooling and ventilating provisions, he must make allowances for such variations either through his own knowledge or by consulting available application data or the supplier of the motor.

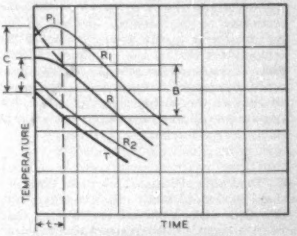

Figure 2. Cooling curves

The inadvisability of basing the temperature-rise value by resistance on certain differences between thermometer and resistance measurements is further indicated by figures 1 and 2 of this discussion. In figure 1, curve *R* gives the time-temperature curve (by resistance) after shutdown, and curve *T* is the corresponding value by thermometer. In this figure it is assumed that the time *t* expires before the first reading can be taken and that we are dealing with a large machine in which the copper temperatures are higher than the temperatures in the core. Both curves are extrapolated toward $t = 0$. If the thermometer is placed at the end connections, which may be the only accessible place, it will be found that the actual temperature is likely to rise for some time after shutdown, as indicated by the portion *P* of curve *T*. This means that the actual difference in operation between the thermometer and resistance values corresponds to *A*, while the difference at the earliest time of measurement corresponds to *B*. If both curves are extrapolated as shown by the dotted lines, we obtain the value *C*. We therefore have three widely different values to choose from, and consequently the final result will be greatly influenced by the procedure followed.

Figure 2 is intended to give similar conditions for a machine in which the core is hotter than the coil portions in the slots. Here the temperature, by resistance, of some coil portions is likely to rise slightly after shutdown, as indicated by the portion P_1 of curve R_1. Curve R_2 corresponds to the value of resistance applying for certain portions of the coils away from the core, while curve *R* may be considered to represent the average of all coil portions. Curve *T* again represents the value determined by

thermometer as it is likely to be in this case. We now can again choose from the values *A*, *B*, and *C*, which widely differ from one another. All of these discrepancies may not be of primary importance in per cent of the total temperature-rises, but the figures merely show that there are some difficulties encountered in an attempt to obtain the difference between the thermometer and resistance measurements with any degree of accuracy.

In the use of the resistance method for large machines, there is one inherent difficulty of considerable practical importance. Frequently the temperature of the test floor varies appreciably and rather suddenly with weather changes; however, the resistance temperatures of large machines will follow such changes only slowly. This will naturally result in errors in the cold resistance of the machine, which is an important factor in the determination of the temperature rise by the resistance method. Since it is not always possible to delay tests until the copper temperature is the same as that of the surrounding air, some discrepancies will be unavoidable, particularly in the larger machines.

C. P. Potter (Wagner Electric Corporation, St. Louis, Mo.): In his paper, Mr. Summers calls attention to the fact that "all the surface measurements on the stator windings of the totally enclosed and totally enclosed fan-cooled motors of table III were obtained with thermocouples which were well distributed in order to locate the hottest point." In other words, "the testing procedure for the enclosed machines was carried beyond the requirements of the ASA standards, because some of the thermocouples were in locations that could not have been reached by inserting thermometers through holes in the frame." He further states that "the recorded winding surface temperatures were approximately 3 degrees centigrade higher on the average than could have been obtained by the thermometer method." The following table shows the results of the temperature tests on the totally enclosed motors, including temperature readings by thermometer which were estimated by assuming that the rise by thermocouple is 10 per cent higher than the rise by thermometer.

	Totally Enclosed Fan Cooled	Totally Enclosed
(*A*) Average temperature rise by thermocouple of hottest winding surface—degrees centigrade	48	39.5
(*B*) Average temperature rise by thermocouple of hottest *accessible* winding surface—degrees centigrade	45	36.5
(*C*) Average temperature rise by thermometer of hottest accessible winding surface—degrees centigrade	40.9	33.2
(*D*) Average temperature rise by resistance—degrees centigrade	46.9	40.1
(*D*—*A*) Difference between temperature rise by resistance and temperature rise by thermometer—degrees centigrade	6	6.9

In appendixes IV and V of his paper, Mr. Summers compares temperature by resistance with the maximum temperature observed by surface measurements on either the windings or core iron. After studying his paper, this seems to be a desirable procedure but it probably accounts for some of the variation in results reported by different manufacturers. Some engineers undoubtedly compare the temperature by resistance with the temperature of the winding surface. If this were done in table IV, the maximum differences between resistance measurements and winding temperatures (at least some of which were taken by thermometer), are eight degrees centigrade in one motor and seven degrees centigrade in two other machines. Similarly, in table IV, when all the winding surface temperatures were taken by thermometer, the differences between temperature rise by resistance and temperature rise by thermometer at full load and the various voltages are seven degrees, seven degrees, and six degrees, respectively. In other words, the differential between winding surface measurements taken by thermometer and resistance measurements seems to be about seven degrees centigrade.

In table III the temperature rise of the laminations of the enclosed squirrel-cage motors is considerably less than the temperature rise of the windings, while in the open and splashproof motors, the reverse is true. It would seem likely that open and enclosed motors of a given rating have magnetic circuits which are more or less alike, and it is probable that the flux densities in the enclosed motors are higher than in the open machines. I would, therefore, like to ask the author, whether there is a possibility that the laminations are more accessible on the open than on the enclosed motors, and whether this may account for the difference in temperatures.

Mr. Summers deserves a great deal of credit for the completeness of his treatment of the determination of temperature rise of induction motors. He has presented a wealth of information in a systematic manner and I agree with him completely in his conclusions and recommendations.

It is gratifying to have so much discussion on the paper on measurement of temperature and to have those who take part in the discussion, agree, in general, with the conclusions reached by the writer. The comments made by Messrs. Hill and Sullivan are very interesting and Messrs. Anderson, Rutherford, and Veinott have given additional data confirming the results reported in the paper. Both Messrs. Rutherford and Veinott have also suggested that the allowance for the hot spot be expressed as a per cent rather than a constant value. This, in the writer's opinion, is a very excellent suggestion and one which should be adopted.

Messrs. Alger and Kilgore have suggested methods of correcting the temperature rise back to the instant of shutdown, and Mr. Alger states that it will be possible to develop correction factors for motor temperature tests similar to those used in transformer practice. This can undoubtedly be done, but it might be well to point out that the two cases are somewhat different. In a transformer the oil circulates due to the difference in temperature between the top of his case and the bottom of the case and this circulation is not immediately interrupted when the temperature test is finished. In a motor the ventilation is produced by the fans on the rotor and this ventilation stops as soon as the temperature test is finished. In the case of an average motor the temperature of the stator iron is ordinarily less than the temperature of the extended parts of the winding. When the temperature test is stopped, the temperatures of the exposed parts of the windings decrease while the temperatures of the stator core increase, indicating that an equalization of temperature is taking place in the machine. It is, therefore the writer's opinion that the resistance in a motor winding does not decrease nearly as rapidly as that of a transformer winding after the temperature test is ended, and it is suggested that this subject be given further study.

Mr. Thomas has commented from the point of view of the motor user and while he agrees that temperature rise should be measured by the resistance method, he does not agree that any higher values of temperature rise be assigned if the change in method is approved. This again is a subject which deserves, and will have, further study before any changes are made in existing standards.

E. R. Summers: In his paper Mr. Potter has presented data and arrived at conclusions which are in close agreement with my test results and recommendations. The following remarks regarding his discussion of my paper do not represent any basic difference of opinion, but are intended only to supplement some of the points which he has mentioned.

Mr. Potter has estimated that thermometers would have indicated ten per cent less winding temperature rise than was actually obtained with thermocouples on the totally enclosed fan-cooled and totally enclosed motors of table III. Nonuniformity of testing practices among different organizations give rise to considerable variations between the temperature differentials obtained by comparing thermometer and thermocouple readings. The leads of several thermocouples can be brought out through one hole in the frame, whereas a separate hole must be drilled for each thermometer used in an enclosed motor. Consequently readings are likely to be obtained at more points with thermocouples than with thermometers, and any general comparison of the two devices usually involves differences in thoroughness of exploration as well as variations in contact with internal parts. Furthermore thermocouples can readily be placed in locations not accessible to thermometers, and dependable comparisons would require exactly the same mounting positions.

Mr. Potter emphasizes the probability that some manufacturers compare temperatures obtained by the resistance method with thermometer measurements taken on the windings only. Such comparisons are not valid, because the thermometer method as defined in the standards includes the hottest surfaces on the laminations as well as on the windings. On the majority of open and splashproof motors, the laminations are hotter than accessible parts of the

winding. To interpret comparative data from different manufacturers, it is therefore essential to ascertain if readings on laminations are included. If lamination temperatures are omitted on open or splash-proof motors, the data cannot be used directly for purposes of standardization.

From my experience, I find that thermometers and thermocouples when used in exactly the same locations with similar protective coverings will give readings which usually agree within the accuracy of the test, or within two degrees centigrade, as indicated in the data for motor *X* in table I.

Mr. Potter has questioned the data on the totally enclosed motors of table III because the indicated temperatures on the laminations are considerably less than on the windings. Since the lamination and winding temperatures are very nearly the same on totally enclosed motors, thermocouples were placed on the windings only. The laminations were not accessible, and the indicated temperatures are lower than the actual values by the amount of thermal drop through the frame as indicated by the asterisk and note at the bottom of table III. These apparent discrepancies in lamination temperatures are indicative of the differences which may be expected when temperatures are measured only on the outside of the frame on totally enclosed motors.

Mr. Kilgore states that winding temperatures change very rapidly in the first few minutes after shutdown, and that test results by the resistance method may vary as much as six degrees centigrade if one tester gets the readings in 0.5 minute and another requires 1.5 minutes after shutdown.

Heat energy is dissipated at a much lower rate after shutdown than when operating at normal load. For a machine operating at a nominal current density of 2,500 amperes per square inch, the initial rate of change of copper temperature during the first few seconds after removing load (while motor is still coasting at full speed) is approximately $0.9\left(\frac{2,500}{1,000}\right)^2$ or 5.6 degrees centigrade per minute. However this high rate of change does not persist for two basic reasons:

1. The thermal capacity of the adjacent insulation and laminations occasions a sharp decrease in rate of change in copper temperature after the first few seconds.

2. The motor ventilation decreases as the machine is decelerated.

In many cases the motor can be stopped in less than one-half minute. The change in average copper temperature during deceleration will seldom exceed two degrees centigrade if the machine is stopped promptly, and part of this change can be accounted for by extending the resistance curve to zero time.

After a motor is stopped the rate of change in average copper temperature is usually less than one degree centigrade per minute for the first ten minutes. Figure 3 of this discussion shows the change in temperature by resistance method after shutdown on eight typical motors representing widely different ratings and types of construction. Zero time indicates the instant of opening circuit breaker to remove load. The dotted portion of each curve shows the time required to stop the motor and obtain first

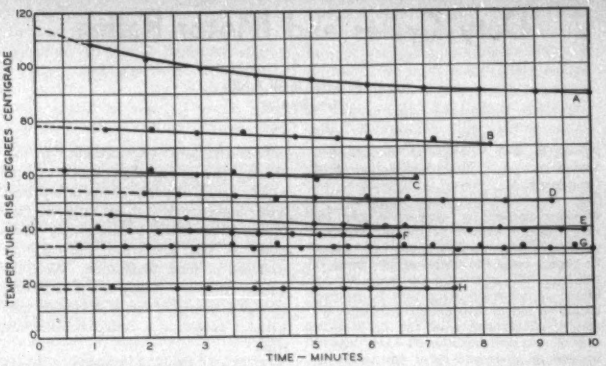

Figure 3. Curves showing change in average winding temperature after shutdown (resistance method)

Curve	Form of Motor Construction	Horse-power Rating	Speed (Revolutions per Minute)
A	Open	25	1,800
B	Splashproof	15	900
C	Totally enclosed fan-cooled	50	3,600
D	Totally enclosed fan-cooled	300	1,800
E	Totally enclosed	60	900
F	Totally enclosed fan-cooled	5	720
G	Splashproof	30	900
H	Open	40	1,800

resistance reading. Curve *A* is the only case where a probable change in temperature of as much as six degrees centigrade is indicated during the first minute, and this occurred on a 40-degree-centigrade-rated 25-horsepower motor that had been operated continuously at 168 per cent of normal load and which had an abnormal temperature rise of 108 degrees centigrade one minute after removing load.

To obtain reliable temperature measurements by either the thermometer or resistance methods, provision must be made for stopping the machine promptly to minimize effects of ventilation by motor fans. It is far more important to decelerate the motor quickly than it is to measure the resistance immediately after stopping, because heat energy is dissipated much faster while the motor is running (except for totally enclosed machines). The difference in resistance readings taken 1.5 minutes instead of only 0.5 minute after stopping motor is seldom more than would correspond to one degree centigrade on enclosed motors or two degrees centigrade on open machines.

The average differentials of 10 degrees centigrade to 15 degrees centigrade which Mr. Kilgore reports between thermometer and resistance methods are much greater than I have observed, and this disagreement in results is probably caused by (1) differences in thermometer exploration, (2) omission of lamination temperatures, and (3) differences in estimated change in copper temperatures during deceleration. Mr. Kilgore's comments would indicate that the 15-degree-centigrade conventional allowance is not sufficient for thermometers, if the resistance readings indicate 15 degrees centigrade higher average temperature than the thermometer method.

Mr. Hellmund's discussion is quite broad, and a number of his general comments apply equally well to all methods of temperature measurement. In the table where he has evaluated the various factors concerned with motor rating, the combined effects of service factor, variations in power supply, and allowance for service mounting are superimposed to arrive at the "conservative" limit of 30 degrees centigrade resistance rating in column *A* for general purpose motors. Under the present standards the 15 per cent (or ten degrees centigrade) service factor is imposed only for normal conditions of power supply and ventilation, and is not intended to apply for abnormal operating conditions. However, his evaluation of these different factors is certainly of pertinent interest.

Since the American and AIEE standards now specify the thermometer method, any general change to the resistance method necessarily involves direct differentials between the two methods. The cooling curves which Mr. Hellmund presents indicate that these differentials are quite indefinite and that widely varying values may be obtained. These curves make the problem appear more difficult than it really is.

The temperature by the thermometer method as now defined in the standards is the highest observed reading on either laminations or windings before or after shutdown, and would correspond definitely to the maximum point on Mr. Hellmund's curve marked *T* which should represent the highest reading thermometer.

The temperature by the resistance method may be defined either as the temperature immediately after shutdown (within a specified time) or as that obtained by projecting curve *R* to zero time. As previously stated the effect of projecting curve *R* to zero time seldom changes the result by more than two degrees centigrade if the motor is stopped promptly, and therefore the values from which one must choose are not widely different.

In the case of large or high-speed motors where no provision can be made to stop them quickly, the resistance method as

Duty Cycles and Motor Rating

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MEMBER AIEE

Synopsis: The horsepower rating of a motor carries a dual implication—first, torque ability; second, temperature rise. The two are frequently confused. In selecting motors for duty-cycle jobs the two concepts should be considered separately. The motor rating and type should be chosen to fit the torque requirements of the job. The proper time rating or service factor to associate with this horsepower rating to insure satisfactory insulation life can be determined from the duty cycle. Use of oversize continuously rated motors instead of short-time-rated motors to secure high torque ability on variable load jobs imposes an economic loss. Frequent starting and reversing or starting high inertia loads imposes a temperature hazard frequently greater than heavy overloads. Horsepower rating as now understood is not a satisfactory criterion of a motor's reversing ability. These topics are developed by means of simple hydraulic analogies.

BY DEFINITION, one horsepower means 33,000 foot-pounds per minute, equivalent to 746 watts. By convention and rules, the term horsepower when used as a motor rating, carries additional implications. In particular, the rating implies first, torque ability, and second, temperature rise. The horsepower rating suggests the ability of the motor from a torque standpoint to start, accelerate, and carry an overload of some magnitude. Also, the motor will carry steady rated load, or a specified overload for a specified time without exceeding a stated temperature rise.

Neither of these implications, nor any rules or generally known conventions, clearly suggest what a given motor will do on a duty-cycle job with a varying load, particularly if starting or reversing constitutes a regular part of the duty cycle. Sometimes, unduly large and costly motors are used to secure high torque ability for a temporary overload. A short-time-rated motor, for example one hour, 50 degrees, of correct size and rating would be more economical. However, if frequent starting or reversing or if starting a heavy flywheel load constitutes a regular part of the duty cycle, there is a distinct tendency to "undermotor" because there is not a general recognition of the heavy overload imposed by such service.

This paper is primarily concerned with what performance may ordinarily be expected from average polyphase squirrel-cage induction motors like those used on machine tools and similar applications when the load is not steady and continuous.

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Torque Ability

In selecting a motor for a particular job, it is expedient and conducive to obtaining better performance or smaller motors, to consider the two concepts, torque and temperature, separately. First choose the horsepower rating from a torque standpoint only without any consideration of temperature. Temperature rise is considered separately later. The motor must have sufficient starting torque to start the load under the adverse conditions of low line voltage and reasonable overload. The motor must have sufficient accelerating torque to bring this load up to full speed. Sometimes the distinction between starting and accelerating torque is not made and higher starting torque than necessary is specified because of experience with another type motor which had low accelerating torque. The motor must have sufficient breakdown torque to carry a reasonable overload with low line voltage without an excessive drop in speed. More than adequate torque ability is an extravagance paid for by other characteristics or increased size.

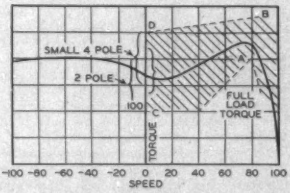


Figure 1. Typical speed-torque curve class A and B motors

There are four readily available classes of squirrel-cage motors:

Class *A*. Normal starting torque, normal starting current (usually made with a single-cage rotor)

Class *B*. Normal starting torque, low starting current (frequently made with a double-cage rotor)

Class *C*. High starting torque, low starting current (usually made with a double-cage rotor)

Class *D*. High starting torque, high slip (almost always single cage)

In this paper we will generally not distinguish between classes *A* and *B* as

previously described is not directly applicable, and imbedded detectors are recommended. Mr. Hill has mentioned the possibility of opening the power circuit momentarily to obtain resistance readings while the machine is running. We have taken some data in this manner which was consistent in every respect. Our experience with this method of taking resistance readings is not yet considered conclusive, but such a procedure does offer a possible means of testing large motors which cannot be decelerated in a reasonable time.

Mr. Hellmund's comments on the difficulty in obtaining dependable cold resistance temperatures are well stated. In general it is more difficult to obtain the "cold" winding temperature within one degree with thermometers when the ambient is changing, than it is to measure the ohmic resistance with comparable accuracy using a suitable double bridge. Mr. Sullivan and Mr. Hill have also carefully discussed the importance of accurate cold temperature measurements.

Mr. Thomas has objected to any addition to the present thermometer ratings to obtain the proposed new ratings by resistance. The suggested increase of five degrees was not intended to represent any expected difference between resistance data and the temperatures which could be obtained by a thorough exploration with thermometers (or thermocouples). This increase is suggested because the resistance method avoids the low readings sometimes obtained by thermometer, and 60 degrees centigrade rise by resistance is considered to be fully as conservative as 55 degrees centigrade rise by thermometer. On the basis of 40 degrees centigrade ambient and 105 degrees centigrade limiting hottest-spot temperature, a resistance rating of 60 degrees centigrade provides a hot-spot allowance of 5 degrees centigrade which tests indicate to be a representative value for totally enclosed motors.

It is very pleasing to note the close agreement between the discussions of Messrs. Potter, Hill, Sullivan, and Thomas. Although not in complete agreement on the proposed differentials and ratings by resistance, everyone apparently agrees in principle that the resistance method is desirable for enclosed and inaccessible machines.

they are usually interchangeable in application.

To establish a reason for selecting a particular horsepower rating and a particular class motor to do a particular job, typical speed-torque curves for average motors are shown in figures 1, 2, and 3. Data are intended for illustrative purposes only, as individual motors may depart appreciably from the average. Points *A* and *B*, figure 1, show minimum and maximum logical values for breakdown torque. It is assumed that any motor should carry some overload, say 25 per cent at 10 per cent reduced voltage, with a reasonable margin for safety, say 20 per cent. Since the motor's torque ability is proportioned to the line voltage squared, we require $1.25 \times 1.2 \div 0.9^2 = 1.85$ or 185 per cent breakdown torque, as tested under normal

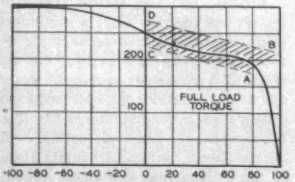


Figure 2. Typical speed-torque curve class D motors

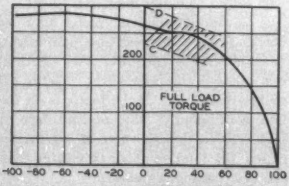


Figure 3. Typical speed-torque curves class D motors

conditions. This is close to the 200 per cent minimum breakdown torque which is now standard for class *A* and *B* motors. It is assumed that a motor would not ordinarily meet the minimum requirements for the next higher standard rating. In the lower range, an average step or ratio of successive horsepower ratings is about 140 per cent. This establishes *B*, figure 1, as 280 per cent for the greatest breakdown torque to be logically expected.

Parenthetically, it should be noted that stray load losses constitute a part of the load on the motor. They appreciably reduce the breakdown torque below the value given by formulas in handbooks which do not recognize stray load losses.

In class *C* motors, breakdown torque is sacrificed to obtain increased starting torque. See figure 2 showing typical values.

With regard to starting torque, the writer knows of no process of reasoning which will suggest a logical value purely on the basis of the horsepower rating. Suitability to the usual application and the necessary compromises of design have established starting torque values for motors as now made. Extravagant starting torque can be obtained only by sacrifice of other desirable characteristics such as efficiency, power factor, or breakdown torque.

In figures 1, 2, and 3 a portion has been shaded to indicate the expected variations of different motors and of different ratings. Points *C* and *D*, figure 1, show the total range of variation in starting torque of class *A* and *B* motors. For different motors of a particular rating the range is of course smaller covering the lower, middle, or upper part of the range shown in figure 1.

Class *A* or *B* motors should be used for jobs not requiring unusually high starting torque, not started or reversed frequently, or not used to start a heavy inertia load. As will be shown later, there are many cases where a short-time-rated class *A* or *B* motor can be used economically.

Class *C* motors are intended for jobs requiring exceptionally high starting torque such as reciprocating compressors. In the smaller sizes, efficiency may be sacrificed, and in the larger sizes, breakdown torque must be sacrificed to obtain this higher starting torque. As will be shown later, class *C* motors can be reversed more frequently than class *A* or *B*.

Class *D* motors are used for a variety of jobs, including:

1. Hoists and similar jobs where maximum starting torque is required with sacrifice in ordinary efficiency.
2. Frequent reversing.
3. Starting, stopping, and reversing high inertia loads such as extractors and centrifuges.

In tentatively selecting the horsepower rating and best class of motor from a torque standpoint, the job should be considered with regard to its requirements for starting, accelerating, and breakdown torque. To allow for a possible 10 per cent drop in line voltage, the rating must be high enough so that 81 per cent of the breakdown torque of the motor is safely higher than the maximum load. (Breakdown torque is proportioned to the line voltage squared.) Also, the speed with this maximum load must not be unduly low. If the rating is three quarters of the maximum load, these conditions are generally fulfilled. Class *A* motors can be temporarily overloaded somewhat more. If unusually high starting torque is not necessary, a class *A* or *B* motor is of course indicated. If higher starting torque is required, a class *C* motor is proper. The horsepower rating must be such that 81 per cent of the starting torque will always start the load. Again, we allow for low line voltage. Whichever of these two specifications, starting or breakdown torque, indicates the higher rating is the factor which determines the rating from a torque standpoint. With polyphase motors and other motors not having low points in the torque curve, extravagant starting torque is not necessary to secure adequate accelerating torque.

Temperature

We must now consider the motor from a temperature standpoint. Is the tentatively selected rating cool? If very cool what short-time-rated motor can be used? As is well known, temperature is limited because insulation deteriorates more rapidly at high temperatures. The insulation should not wear out while the motor is otherwise modern and usable. Insulation deterioration is a function of time as well as temperature. Thus the temperature rise during a short period may safely be somewhat higher than conventional values if compensated by much longer periods during which the temperature is much lower.

The newer synthetic insulation ma-

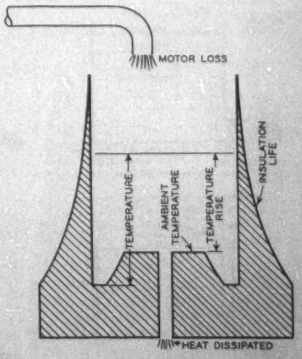


Figure 4. Hydraulic analogy illustrating temperature rise

terials now being used in motors have longer useful life than materials used a few years ago. Today enamel in combination with cellulose is generally used for wire insulation. This enamel is better and more generally used than when present temperatures were standardized. With all the developmental work now being done, it is not unreasonable to expect improvements to continue.

Figure 4 presents a hydraulic analogy to explain temperature rise. (Some distortion of the laws of hydraulics is necessary to make the analogy mathematically correct.) Water flowing into the tank is illustrative of the motor losses. Watts loss in the motor is analogous to cubic feet per minute water flow. The total kilowatt-hours energy loss is illustrated by the total cubic feet of water. The height of water in the tank is analogous to temperature. The capacity of the tank is illustrative of the heat storage capacity of the motor, proportional to the summation of the weight of the parts multiplied by their specific heat (weighted for temperature differences). The outlet at the bottom is illustrative of the heat dissipation by radiation, conduction, and convection. Obviously, the water rises to a level so that the outflow balances the inflow, that is, the temperature is steady.

Note that the walls of the tank are not of uniform thickness. This suggests the time factor in insulation deterioration. The slow rusting or corrosion of the walls is analogous to wearing out of the insulation. (The scale for insulation life is distorted to keep the diagram reasonably small.) The diagrams which follow are simplified by showing a tank with a thin wall. The reader should remember that a tank like figure 4 is always implied to represent more closely the fact that insulation wears out because of high temperature for a long time.

In figure 5, the analogy is elaborated to bring in more detailed factors. Losses flow into the tank from two pipes—first no load losses and second extra losses due to carrying a load. It is a quite accurate common assumption that the extra losses due to load are proportioned to the load squared. The heat dissipation is divided into two parts—the dissipation when the motor is not running and the extra dissipation due to extra ventilation when the motor is running. Valve *A* is analogous to the line switch. *A* and *C* are tied together to indicate "turning on" the ventilation when the motor is started. Valve *B* is opened more or less to indicate more or less load.

Figure 5*A* pertains to an average normal or high-speed motor, say 1,200 to 3,600 rpm. Figure 5*B* indicates the changed proportion of the factors for a slower speed motor, say 450 to 900 rpm of the same physical size but lower horsepower rating. Note the greater losses at no load and the lesser ventilation.

Figures 5*C* and 5*D* illustrate short-time-rated motors made in the *same size parts* for which figures 5*A* and 5*B* indicate continuously rated motors. The horsepower rating is higher, the torque ability, that is, starting, accelerating, and short-time overload ability, are increased. When operated at the increased rated load, the losses are higher as indicated by the larger inflow pipes. Since the heat dissipation ability is not increased, obviously the motor cannot be operated at rated load continuously without exceeding ordinary temperature limits. According to the conventional rating, say one hour, 50 degrees centigrade, the motor is started cold and at the end of one hour the energy losses have been either stored in the parts or dissipated so that the motor has just reached its temperature limit. In typical industrial applications there is seldom such a duty cycle. Usually the motor is operated with varying load or intermittently so that after a period the motor settles down to a continuous average temperature. In the analogy valves *A* and *C* may be open all or part time to indicate either continuous or intermittent operation. Valve *B* is turned off and on varying amounts according to the actual load. The height of fluid rises to an average level which is maintained because on the average just as many cubic feet of water flow in as flow out.

Normal and high-speed one-hour motors will generally carry a continuous load as high as the continuous rating associated with the size parts. For example, a 5-horsepower continuous motor and a $7\frac{1}{2}$-horsepower one-hour motor are usually made in the same size parts. The $7\frac{1}{2}$-horsepower one-hour motor will generally carry continuously as much load as the 5-horsepower continuous motor. However, the torque ability is increased to take care of short overloads and abnormal conditions. Thus the one-hour motor is well suited to many industrial loads.

A slow-speed one-hour motor may not carry, from a temperature standpoint, as much load as the lower rated continuous motor in the same parts. Figure 5*D* makes this clear. If the motor is on the line continuously, the no-load loss is high. Even though valve *B* is partially closed, the total loss may be greater than the heat dissipating ability.

The short-time conventional temperature test is not always an exact criterion of the merit of a motor. Figure 6*A* is analogous to a motor which is large and heavy for its rating with inferior ventilation. At the end of the conventional test, the temperature is not excessive since the motor has excess heat-energy storage capacity (that is, a large tank). On an actual intermittent load the motor operates hot due to poor ventilation

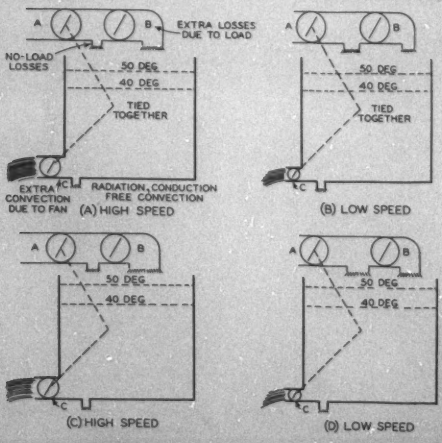


Figure 5. Hydraulic analogy illustrating factors affecting temperature rise

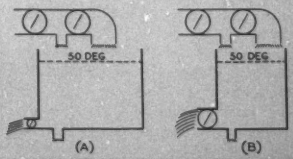


Figure 6 (right). Hydraulic analogy illustrating heavy poorly ventilated and light well-ventilated short-time-rated motors

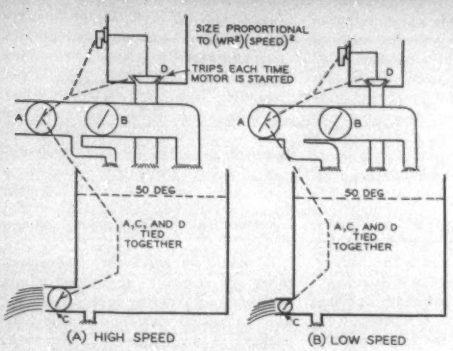


Figure 7. Hydraulic analogy illustrating extra losses due to starting

(small outflow from tank). Figure 6*B* indicates a lighter-weight well-ventilated motor which when tested by the conventional short-time test seems to be inferior as the temperature is high. On the actual varying load it operates cool because it is well ventilated.

Service Factor

Probably the economically sound field for these intermittent-duty motors is broader than their present range of use. Lack of a definite descriptive nomenclature which clearly indicates the ability of the short-time-rated motor on an intermittent load is possibly one of the largest detriments to the more extended use of these smaller, lighter, high-torque-ability motors. Obviously a slow-speed short-time-rated motor will not carry as much load with a safe temperature as a higher-speed motor which passes the same conventional test. It is not to be expected that all users of motors are sufficiently informed regarding details of design and application to use safely these more economical motors without fear of excess heating. Thus there exists a distinct tendency to "overmotor" from a heating standpoint in order to obtain a safe margin in torque ability.

There is a term in current use, the meaning of which can be broadened to indicate more definitely what these motors will do. The frequently quoted 1.15 service factor clearly indicates that the normal motor to which it is applied will carry 115 per cent rated load without exceeding recognized safe temperatures. A service factor less than unity would indicate that the motor must be loaded less than its rating continuously in order to maintain normal temperature limits. Of course, the load may be either continuous or a varying load of the same root-mean-square value.

If the job does not include frequent starting and reversing or starting high inertia loads, there is no hard problem in selecting the motor from a temperature standpoint. Merely calculate or estimate the root-mean-square load and see that the motor rating multiplied by the service factor is at least as high. For the purpose of this paper (root-mean-square horsepower load) is defined as

$$\sqrt{\frac{\Sigma\,(\text{hp})^2 \times \text{time}}{(\text{running time}) + \dfrac{(\text{standstill time})}{\text{constant}}}}$$

For the numerator each part of the duty cycle is considered separately. Take the sum for all parts of the cycle of the square of the horsepower load multiplied by the time for this element of the cycle. The constant in the denominator is the ratio of heat dissipation running to standstill, frequently assumed to be 4. Slightly higher values may apply to high-speed motors and lower values apply to low-speed motors. For enclosed motors without fans this constant is not much greater than one.

For application purposes, normal and high speed, one-hour motors may be assumed to have 80 per cent service factor. This factor is derived by the following reasoning: The standard motor has 1.15 service factor. The one-hour rating averages 140 per cent of the continuous rating in the same size parts. The one-hour motor will dissipate continuously as much loss as the continuous motor and the efficiency is essentially constant. Hence, the service factor of a one-hour motor may be assumed to be 1.15/1.4 = 0.82. We use 0.8.

Starting and Reversing

In the above all starting and reversing operations in the duty cycle are not included. The losses due to these operations are included separately. Frequent starting and reversing or starting a high inertia load imposes a severe temperature hazard, often more severe than a heavy overload. In figure 7 our hydraulic analogy is extended to illustrate the extra losses due to starting. As is well known, the stored energy in the rotating system constitutes a fundamental unit in acceleration problems. The stored energy is $3.87 \times 10^{-6}\,(WR^2)\,(\text{rpm})^2$ watt minutes. WR^2 is in pound feet squared. Each time a motor is started one of these units is supplied to the rotor in the form of heat. There are additional losses in the stator. Total losses for starting class *A* and *B* motors will average 2 to $2^1/_2$ times the rotor loss. With class *D* motors total losses will be $1^1/_4$ to $1^1/_2$ times the rotor loss. Class *C* motors have intermediate values.

In our hydraulic picture, figure 7, each time the motor is started, valve *D* is tripped, thus increasing the average inflow, analogous to increasing the average loss. Of course, valve *B* must be closed part of the time or the water will rise higher in the tank, that is, the ordinary load must be decreased to keep the temperature down to what it is for normal operation. Figure 8 shows a picture for reversing a motor. It differs from figure 7 in that the sudden inflow is four times as much.

The accelerating or reversing loss is proportional to the total WR^2 of the rotating system, including the motor and its load and proportional to the number of equivalent reversal per minute counting a start as one-quarter reversal.

We have not shown a picture for operation of a short-time motor, say one hour, on a reversing job. In fact, the terms become ambiguous. The motor is seldom

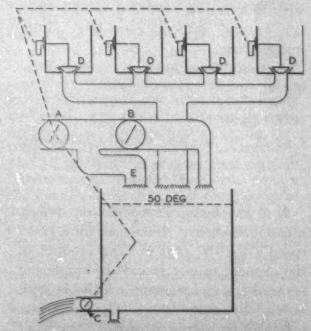


Figure 8. Hydraulic analogy illustrating extra losses due to reversing

Table I

Assumed		3,600 RPM			1,800 RPM			1,200 RPM					
			Assumed			Assumed			Assumed			Assumed	
Horsepower	Efficiency	$(WR^2)N$	WR^2	N	$(WR^2)N$	WR^2	N	$(WR^2)N$	WR^2	N	$(WR^2)N$	WR^2	N
2	82	0.84	0.2	4.2	3.4	0.6	5.6	7.6	1.5	5.0	13	2	6.7
5	85	1.7	0.5	3.4	6.8	1.5	4.5	15	3.8	4.0	26	5	5.2
15	88	3.9	2.0	1.9	16	6.0	2.6	35	15	2.4	62	20	3.1

if ever operated for only one hour as the rating implies. It is in fact used for an all-day job. The load may be light and variable but the operation is continuous. Hence, reversing service should be specified in terms of ultimate temperature.

What is the magnitude of these extra losses due to reversing? No reasoning based solely on the implications of the rating will indicate the reversing ability of a particular motor without knowledge of some of the details of design. We can assume that if the reversing losses are greater than the normal losses at full load, the motor is carrying the equivalent of an overload and normal temperature margins are reduced.

Let us work out a specific case, say of a class *A* five-horsepower, 1,800-rpm motor with 85 per cent full-load efficiency and with total WR^2 including load, 1.5 pound feet squared. Assume that the total reversing losses are $2^1/_4$ times the rotor losses. The loss in watt minutes for one reversal is:

$$4 \times 3.87 \times 10^{-6} \times 1.5 \times (1800)^2 \times 2^1/_4 = 168$$

The loss due to normal operation at 1.15 load, as permitted by the service factor is:

$$5 \times 1.15 \times 746 \times 0.15/0.85 = 767 \text{ watts}$$

Thus one interpretation of the rating indicates that the motor can be reversed with this inertia, 767/168 = 4.5 times per minute without exceeding normal temperature.

A general formula based on this reasoning is:

$$(WR^2)\,(\text{rpm})^2 N = \frac{4.82 \times 10^7\ (\text{service factor})\ (\text{horsepower rating})\ (1 - \text{eff.})}{K \times \text{eff.}}$$

K is the factor dependent on design, mentioned above. Note that for a given speed $(WR^2)N$, that is, the product of the moment of inertia and the number of reversals is a constant. This is well verified by many tests. Note also that this is an optimistic estimate of reversing ability. We have assumed that the motor will dissipate as much loss due to reversing as the losses due to continuous operation. If reversed very frequently, the ventilation is impaired as the average speed of the ventilating fan is decreased. This is analogous to continually opening and closing outlet valve *C*, figure 8. In deriving the formula for losses due to reversing, we have neglected friction and windage losses, core loss, and magnetizing current together with extra I^2R loss in the stator caused thereby. This is analogous to closing permanently spigot *E*, figure 8. For high-speed motors, this is not serious. However, it is a considerable factor for slow-speed motors. In our analogy the tank is already partly filled by these neglected losses. Only the remainder is available for reversing losses. Thus while the number of reversals with a given WR^2 is increased with lower speeds, the increase is not proportional to the square of the speed ratio as suggested by the above approximate formula.

Table I shows reversing ability of a variety of class *A* motors in accordance with the assumptions above.

The assumed WR^2 includes both motor and load.

N is the number of reversals per minute to give the same losses as normal operation at 115 per cent load.

This table has been prepared primarily to indicate that frequent reversing of standard general-purpose motors constitutes an overload beyond the implications of the name plate. There is not a general recognition of how much this overload is. Of course more reversals than tabulated can be obtained if the inertia of the load is small, thus reducing the total WR^2. Other kinds of motors are better adapted to frequent reversing. The class *C* motor will give distinctly more reversals and still maintain good efficiency in the operating range. Class *D* motors will give maximum number of reversals but the efficiency is lower at normal speed.

Of course, special motors can be made primarily for reversing service to give many more reversals. The principles involved are well known to designing engineers. No discussion of these is included here, as this paper is primarily concerned with the use of general-purpose motors.

It should be noted that horsepower rating as generally understood is an unsatisfactory criterion of reversing ability. In fact, it may be distinctly misleading. A small motor will give more reversals than a larger homologous motor if the load WR^2 is small. In general, those factors which are conducive to obtaining high reversing ability are exactly contrary to maintaining the normal margins for normal operation usually associated with a given horsepower rating. In fact, strange as it may sound, a lower horsepower rating is frequently consistent with greater reversing ability. One such case is associated with the reversing of slow-speed motors. See figure 8. The tank is already partially filled by no-load losses from spigot *E*. If no-load loss fills the tank three-quarters full, only one-quarter is left for reversing. Now if the torque ability is decreased to two-thirds of its former value, the tank is only half filled by no-load loss leaving half a tank for reversing. Thus, the reversing ability from a temperature standpoint is doubled, but the normal margin in torque ability is sacrificed.

Starting High-Inertia Loads

We have discussed frequent starting and reversing where the instantaneous temperature is close to the average. Starting high-inertia loads such as extractors imposes extra transient temperatures higher than the average. The average temperature rise is determined by the same considerations as for rapid reversing jobs. Figure 9 shows a hydraulic analogy. It differs from figure 7 in that the tank is divided into three compartments to simulate the separate heat storage capacity of the stator and rotor windings and core. The three compartments are connected by ports so that ordinarily no great difference in level can exist, that is, the temperatures of the parts of a motor are quite uniform for ordinary operation.

In figure 9 the extra inrush of water into the stator and rotor compartments simulates the extra starting loss in the

motor due to starting a high-inertia load. The rotor losses flow into the rotor reservoir and the stator losses into the stator compartment. The loss is proportional to the load WR^2, hence high. All compartments are already partially filled. The extra inrush may cause one to overflow before the water can run into the others or be dissipated. Consider for example, the rotor losses which are: $3.87 \times 10^{-6}(WR^2)(\text{rpm})^2$ watt minutes. The size of the rotor reservoir is (weight of rotor windings) × (specific heat) × (safe temperature). What is a safe rotor temperature? Some of the factors which must be considered are melting point, latent heat of fusion, tensile strength at high temperatures, deterioration of alloys by change in composition or crystalline structure. It is a coincidence that the size of the rotor reservoir is about the same for the different commonly used materials. Copper will stand high temperatures but the weight for satisfactory characteristics (high resistance) is low. Aluminum melts at a lower temperature but it has outstandingly high specific heat and latent heat of fusion. Brass is heavy for a given resistance but it will not stand repeated high temperatures.

The transient stator temperature is determined by similar details of design. Of course, even transient temperatures must be held to values which will not wear out the insulation too rapidly. It is quite difficult to determine the peak transient temperature. In figure 9 we indicate the analogy to a thermometer inserted on the stator winding. A thermometer reads a temperature because its mercury gets hot and expands. Thus there must be a thermal lag in reading with rapidly changing temperatures as illustrated by the small passage between the thermometer and stator reservoirs.

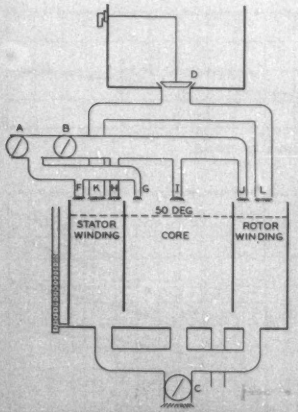


Figure 9. Hydraulic analogy illustrating extra losses due to starting a high-inertia load

These details have been discussed to indicate that design details rather than horsepower rating determines the ability of a motor to start and operate machines with high inertia. Standard motors are not ordinarily used for such service. Standard motors are designed for good characteristics at normal speeds. What ability they have to reverse frequently or to start high-inertia loads is a variable by-product of design.

Built-in Motors

A short statement is necessary regarding the operation of any motor on any job when that motor is built in as a part of a complete machine. In our hydraulic picture, the motor designer controls the size of the inflow spigots, *A*, *B*, and *D*. The machine designer controls the size of the outflow spigot. The user determines how frequently and how much the valves are opened. No one of the three can say how full the tank will be. This indicates that the performance of such motors from a temperature standpoint is a matter of divided responsibility.

Summary

1. When selecting motors for duty-cycle jobs, the two concepts, torque ability and temperature rise should be considered separately. The class or type and the rating should be such that there is no deficiency or undue extravagance in starting, accelerating, or breakdown torque ability. If the root-mean-square load is appreciably less than the motor rating required from a torque standpoint, a proper short-time-rated motor is economical.

2. Frequent starting and reversing or starting high-inertia loads frequently imposes the equivalent of an overload from a temperature standpoint.

3. The data and analogies given in the paper show that performance of a motor on starting, reversing, or other duty cycles is not clearly evident from the horsepower rating alone. The usual method of giving a motor a short-time rating is also inadequate for determining its performance on duty-cycle jobs.

4. It is suggested, therefore, that motors for duty-cycle service be given horsepower ratings representative of their over-all torque ability regardless of heating. It is suggested that service factors be used to indicate the load they can carry continuously within their proper temperature limits. Under this plan, a motor now rated one hour 50 degrees, would become a motor with the same horsepower rating but with, say, 0.8 service factor. This proposal forms a logical extension of the present plan of giving service factors higher than unity to general-purpose motors applied in continuous service on special applications.

Appendix A

Rotor loss during speed transients

$$T = J\frac{d\omega}{dt}$$

$$Tdt = Jd\omega$$

Rotor power loss $= T(\omega_s - \omega)$

Rotor energy loss

$$= \int_{T_1}^{T_2} T(\omega_s - \omega)dt$$

$$= J\int_{\omega_1}^{\omega_2} (\omega_s - \omega)d\omega$$

$$= J\left[\omega_s\omega_2 - \omega_s\omega_1 - \frac{\omega_2^2}{2} + \frac{\omega_1^2}{2}\right]$$

If $\omega_1 = 0$, $\omega_2 = \omega_s$, that is, start from rest and accelerate to full speed, rotor energy loss $= J\omega_s^2/2$.

If $\omega_1 = \omega_s$, $\omega_2 = -\omega_s$, that is, a complete reversal, rotor energy loss $= 2J\omega_s^2$.

Converting to watt minutes, WR^2 in pound feet squared and revolutions per minute, watt minutes rotor energy loss for one reversal is

$$\text{Watt minutes} = 1.55 \times 10^{-5}(WR^2)(\text{rpm})^2$$

T = torque in pound feet
J = moment of inertia in pound (gravity) feet^2
ω = angular velocity in radians per second
ω_s = synchronous angular velocity
WR^2 = pound feet^2
t = time
T_1 and T_2 = initial and final time

Discussion

C. G. Veinott (Westinghouse Electric and Manufacturing Company, Lima, Ohio): Mr. Hildebrand's paper showing how difficult it may be to predict the temperatures in a motor of varying duty cycle suggests how fortunate indeed is the builder and user of fractional-horsepower motors. The maker of refrigeration or air-conditioning equipment invariably builds one or more samples of his appliance which can be subjected to all kinds of tests in the laboratory, both at elevated and at subnormal ambient temperatures. Usually these tests involve the use of a large number of thermocouples and one more can readily be added to the motor winding. Thus it is possible to determine by laboratory test, just what the winding temperatures of the motor will be in service. The problem is even simpler for the refrigeration manufacturer if he uses a motor properly equipped with an inherent overheating protector which allows the maximum useful output to be obtained from the motor windings, without endangering the windings whatsoever.

Temperature Limits Set by Oil and Cellulose Insulation

CHARLES F. HILL
MEMBER AIEE

Synopsis: The life of cellulose insulation in oil has been investigated as a function of temperature under conditions of free access to oxygen and also in an inert atmosphere. Temperatures up to 140 degrees centigrade have been used. An attempt has been made also to study the life of oils as a function of oxygen concentration in an actual transformer at various temperatures. The amount of oxygen to produce a given acidity was also determined. On the basis of these data on oils, an attempt has been made to calculate rates of oxygen absorption by oil which may be used to estimate the relative deterioration in transformers of other dimensions. The results show cellulose deteriorates only mechanically, retaining its electrical properties. It is subject to both temperature and oxidation effects, the temperature effect, of course, taking place above 105 degrees centigrade.

THE continuous rating and also the overload rating of electrical apparatus is largely determined by the insulation. Fortunately, in transformers the very large heat capacity of the cooling liquid plus a high rate of heat transfer to the liquid from the metal parts permits a high overload for short periods of time, but even there, the solid insulation should be protected from too excessive temperatures. It must be recognized that a large fraction of the strength of the solid insulation can be lost in a short time at temperatures which can exist under overload condition. This has been recognized in some instances by the addition of protective devices, thermally operated.

The temperature at which these devices should operate and also the continuous operating temperatures, which would permit a reasonable life of the insulation, are as yet rather arbitrarily fixed by accumulated experience and short-time tests. Conclusions from operating experience are not based on ideal conditions. The amount of insulation deterioration permissible is also an undetermined factor in predicting insulation life. Montsinger[1] and Bush[2] have attempted to determine rates of deterioration which could be extrapolated with time to predict the life of insulation as a function of temperature. A recent paper by Putman and Dann[3] will also be of interest, particularly from the standpoint of overload temperatures.

It is not the purpose of this paper to draw very definite conclusions as to temperatures permissible, but rather to separate the deterioration processes which affect oil and cellulose insulation. Some idea of the temperature limits imposed by these separate processes may be obtained and possibly some conclusions can be drawn from the combined effects. An attempt has been made to cover both ideal and adverse conditions of operation.

Insulating oils and cellulose have been used almost exclusively in transformer equipment as insulation. Because of this and because of their very well-known limitations, an enormous volume of research has been done on these materials, which, when we consider the extent of the research and the improvements in the materials, is somewhat discouraging. Their limitations remain the same. The conclusion is again, that improvements in their behavior in transformers will be gained largely by providing better conditions under which they are to operate.

All of the materials to be considered here are organic in nature, but they differ somewhat in their behavior toward conditions existing in transformer operation. For example, the cellulose molecule contains hydroxyl groups which under severe temperature conditions, may be split off as water. "Chemically combined water" is the term usually applied to such hydrogen-oxygen combinations. Oils, on the other hand, are not subject to such deterioration as they do not contain oxygen in their pure state. They contain only hydrogen and carbon, but are capable of reacting with oxygen to form peroxides and organic acids and other deterioration products. Some of these oxidation products may also polymerize and sludge, a final product, is the result. The peroxides in particular and perhaps some of the low-molecular-weight acids, react with cellulose to cause its decomposition.

Oils in the absence of oxygen can withstand temperatures far in excess of any permissible operation conditions, but the presence of oxygen becomes a serious handicap. The results to be presented

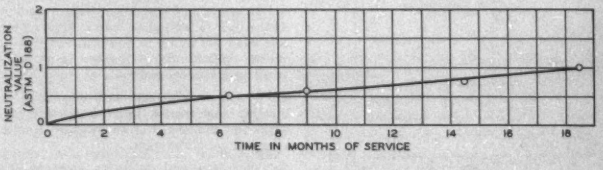


Figure 1. Acidity of transformer oil at 85 degrees centigrade—allowed to breathe once per week

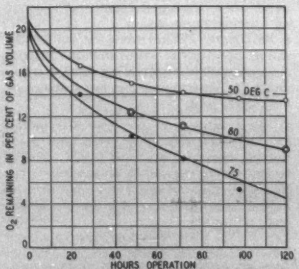


Figure 2. Residual O_2 in gas space

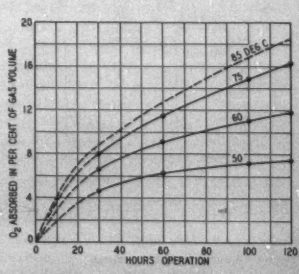


Figure 3. O_2 absorbed from gas space

Paper number 39-16, recommended by the AIEE committee on electrical machinery, and presented at the AIEE winter convention, New York, N. Y., January 23–27, 1939. Manuscript submitted November 1, 1938; made available for preprinting December 8, 1938.

CHARLES F. HILL is manager of the insulation division in the research laboratories of the Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa.

The author is indebted to J. G. Ford of the Westinghouse research laboratories for much of the experimental data.

1. For all numbered references, see list at end of paper.

are given with the intention of emphasizing the oxygen hazard.

The experiments which concern oil alone are of interest in that they show a new method of attacking the problem of determining rates of oxidation. They also apply directly to oil in transformers which is somewhat more convincing than laboratory tests. The oxidation also takes place by contact of oil with air as it exists in the transformer. Two transformers were operated with the same conventional transformer oil. Figure 1 shows the acid accumulation in a 100-kva unit containing 93 gallons of oil, for 19.5 months with approximately one day per week off load. The one milligram KOH acidity was thus produced in approximately 16 to 17 months actual time at 85 degrees centigrade. Its oxygen absorption was 0.48 cubic foot per week or per cycle. The surface of the oil had an area of 3.47 square feet, or an average of 0.138 cubic foot of oxygen per square foot of oil area per week.

The second transformer was operated until the oil had passed its initial latent period when the gas space was blown out and sealed with a fresh air supply. It was then operated for several days, the residual oxygen in the gas space being determined periodically.

Figure 2 shows the data for 50, 60, 70 degrees centigrade for 120 hours and figure 3 is the same data graphed in terms of oxygen absorbed. The 85-degree-centigrade curve was obtained by extrapolation of the intercepts of the other curves. The rates of oxygen absorption of figure 4 are obtained by taking the average at points on the curve for a 20-hour period, 10 hours on each side of the point in question. The data of figure 4 are not to be considered highly accurate, but are approximate values which may be used in estimating oxygen absorption as a function of oxygen concentration. This transformer was operated until the average oxygen consumption could be determined which would produce a definite acidity. This amounts to 0.4 cubic foot of oxygen per gallon of oil for one milligram KOH acidity.

An interesting calculation can be made by assuming the oxygen absorption in the larger transformers takes place chiefly at the oil surface or is proportional to the area. It is recognized that much oxygen absorption takes place in the oil condensed on the tank walls, but in general these will be proportional to the oil area. The hourly rate in the large transformer was 0.138 cubic foot per square foot per six-day week or 0.0009 cubic foot per square foot per hour. Calculating the rates on the vertical axis of figure 4 in terms of cubic feet per square foot per hour it is found that the intercept of 0.0009 from this axis on the 85-degree curve is at about six per cent oxygen concentration. The conclusion is that a six per cent oxygen concentration continuously will give a one milligram KOH acidity in such a transformer in 16 or 17 months. A one per cent concentration at the same temperature would give an absorption of 0.000168 cubic foot per square foot per hour. This will require 5.4 times as long or about 86 months to give the one milligram KOH in the same transformer. The ratio of oil volume to surface determines the rate at which acidity builds up in the oil for any otherwise constant condition.

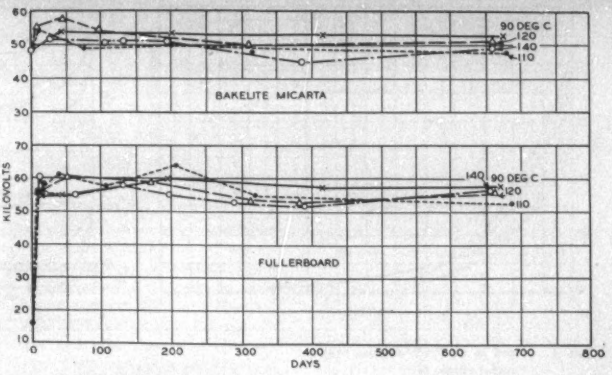


Figure 5. Breakdown tests

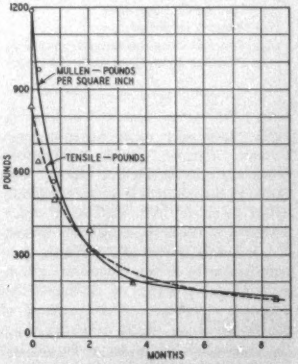
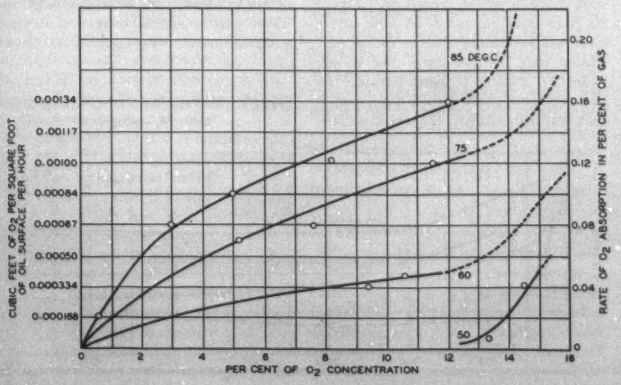


Figure 6. One-eighth-inch fullerboard in oil at 95 degrees centigrade—in air

Figure 4. Rate of O_2 absorption


85 DEG C.
75
60
50
CUBIC FEET OF O2 PER SQUARE FOOT OF OIL SURFACE PER HOUR
RATE OF O2 ABSORPTION IN PER CENT OF GAS
PER CENT OF O2 CONCENTRATION

Life Tests on Cellulose

Cellulose, like oil, is subject to oxidation. Unlike oil, it shows deterioration

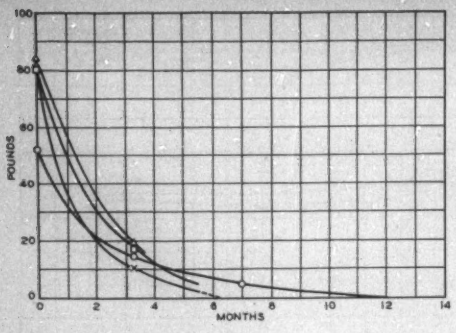


Figure 7. Aged in air (125 degrees centigrade) tensile tests

○—Untreated cotton tape
×—Yellow varnished tape
□—Number 3 varnished tape—one dip
Δ—Number 3 varnished tape—two dips

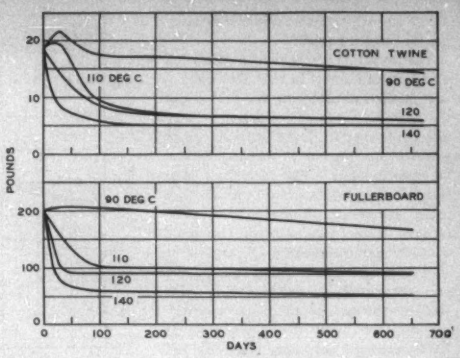


Figure 8. Tensile strength, aged in oil—N_2 atmosphere

from temperature alone and at temperatures which may easily exist in transformers. Further, rapid deterioration sets in at rather fixed temperatures. This is due to the removal of what is generally called chemically combined water which, if carried to the limit, leaves only carbon. If cellulose is heated in a perfectly tight transformer to such a deteriorating temperature, this water of decomposition becomes a problem. Some measure of the deterioration might be obtained by the amount of this water given off, but in the end such data would have to be correlated with the properties of cellulose which are important to its use; namely, its mechanical and electrical properties.

In the present study, some impregnated cellulose materials have been included as well as untreated cellulose. The samples were immersed in oil, and the combination exposed to various temperatures and conditions as shown. The data are recorded in figures 5 to 12. Some samples were heated in contact with oil in air while a special large group was tested in oil in a nitrogen atmosphere, by placing them in small containers which in turn were in large, gas-tight tanks. The nitrogen atmosphere was obtained by a small constant flow from a tank, the oxygen content kept to a low value of the order of 0.1 per cent. The tank at 110 degrees centigrade gave erratic results due to lack of temperature and oxygen control early in the test, but some of the data are shown.

Several mechanical tests were used on the insulations with the most emphasis on the tensile strength. The Mullen test is a bursting test as used on fibrous materials for containers. Some attempt was made at embrittlement measurement and it is believed more emphasis should have been placed on such tests, particularly on treated fabrics. The compression test on shellac Micarta tubes (figure 10) demonstrated this to some extent. Electrical breakdown and resistance constituted the electrical tests.

The conclusion from this set of life tests is demonstrated by a few sample data. Electrically, both treated and untreated cellulose maintain their initial characteristics and may even improve. This is true up to 140 degrees centigrade in the inert-gas tests. By the mechanical tests, however, the untreated cellulose is shown to deteriorate rapidly above 100 degrees centigrade. The deterioration is rapid at 95 degrees centigrade with the oil exposed to the air.

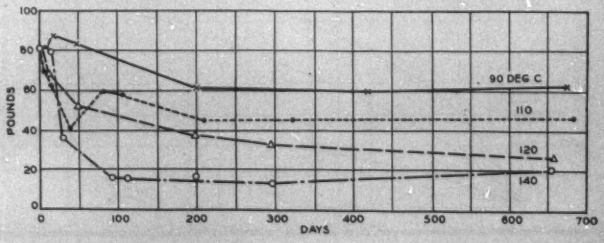
A further example of this mechanical deterioration is found in figure 12 where paper tape is tested at 90 degrees, 120 degrees, and 140 degrees centigrade in a nonoxidizing insulating liquid. The tests were made in sealed containers. Figure 10 gives data on varnished tape under inert gas conditions and is to be contrasted with the 125-degree test in air, figure 7. Figure 11 demonstrates the heat resistance of the varnish and possibly that varnish retards the cellulose deterioration under heat. At any rate, the combination retains its mechanical strength.

Figure 5 and figure 11 demonstrate the type of results on electrical test; namely, that electrically, the insulations retain their properties and even improve.

Figure 6 and figure 7 show the very rapid deterioration of materials in oil exposed to air. This deterioration takes place on the untreated cellulose even before serious acidity is developed in the oil, due, we believe, to the effect of oxygen carried to the cellulose by the oil itself through the formation of peroxide.

Figure 8 is a further demonstration of the mechanical deterioration of cellulose under heat and shows the existence of the critical range of temperature between 90 degrees and 110 degrees centigrade. This is further borne out by the data of figure 12 when the cellulose was again exposed to temperature in a nonoxidizing liquid in sealed containers. There was a small amount of oxygen available in the test of figure 12 as the gas

Figure 9. Shellac Micarta tubes—compression test; N_2 atmosphere



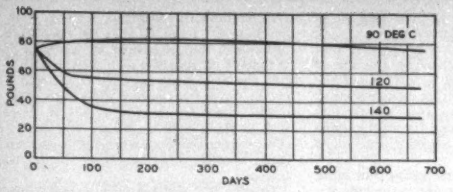


Figure 10. Yellow treated tape—tensile strength, N_2 atmosphere—in oil

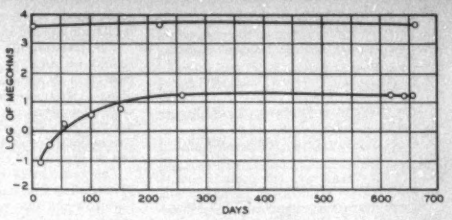


Figure 11. Number 1 varnish cloth—110 degrees centigrade, N_2 atmosphere

above the liquid was air in about the same ratio to oil volume as is found in a sealed transformer.

The data of figure 9 obtained by the force to collapse shellac-paper tubes and also some bending tests in which strips of treated materials were bent to rupture, showed definitely the hardening and embrittlement of impregnating material.

The conclusions from these tests on cellulose and impregnating materials when these tests are combined with experience at lower temperatures, can be condensed into a rather general statement; namely, that up to approximately 90 degrees centigrade, the life of such materials is satisfactory. Above that temperature, mechanical deterioration on bare cellulose becomes rapid, but impregnations protect cellulose to some extent at the elevated temperatures. It is also to be concluded that oxygen restriction is very important to cellulose as well as to oil, and that, while heat alone will mechanically deteriorate the solid insulations at 100 degrees centigrade and above, the presence of oxygen produces deterioration of both oil and cellulose below this temperature.

The method by which oxidized oil affects cellulose is not well understood. The usual impression is that the organic acids are the cause of deterioration and no doubt they have some effect. Stager[4] and Frances and Garrett[5] have discussed this and oil oxidation in more detail, but it now appears the earlier stages of oil oxidation are the more effective.

Predicting the life of a transformer on the basis of the rate of mechanical deterioration is somewhat difficult. However, the insulation is usually used in compression and not for mechanical binding and experience shows that transformers continue to operate after the insulation has reached the very serious apparent deterioration of one-fourth or less than one-fourth of its initial value. This last statement is true for even the best varnished insulations in which the varnish is largely a surface coating.

The results on cotton twine and fullerboard in figure 8 where the oil was exposed to a nitrogen atmosphere, show that untreated cellulose seems to reach a minimum strength of about 25 per cent at 140 degrees centigrade. Further, the decrease took place largely in 100 days. It has since been suspected that the residual oxygen absorbed in the oil may have played a part in this early deterioration, but that is yet to be proved. Our conclusion would be that several hundred hours of operation at 120 degrees to 140 degrees could be permitted for the conditions of an oxygen-free space which may be sufficient to take care of overload periods. Figure 12 gives somewhat the same type of results for the fireproof liquids except that the deterioration was somewhat more. There, however, a small amount of oxygen was present. The leveling off of the mechanical deterioration is largely a dehydration effect in the nitrogen-atmosphere tests.

The extrapolating of such data on solid insulation would seem questionable since it is believed conditions and rates of deterioration change from time to time. It is also uncertain what limits should be reached in an extrapolation of mechanical deterioration. It is the author's opinion that a very large number of transformers in service for a period of years contain fibrous insulation with mechanical strength reduced to 50 per cent of the initial value and in some cases, less than 25 per cent, but function satisfactorily. Some of the insulation from the tests at 140 degrees centigrade in oil with an inert atmosphere would no doubt operate satisfactorily. Such insulation retains good electrical properties. The intrusion of moisture is not to be considered a deterioration, but rather a contamination.

Summary

The experimental data given attempt to show two types of deterioration of cellulose or other organic insulations in transformers. Below 90 or 95 degrees centigrade, such solid insulations would have a very long life under an inert atmosphere.

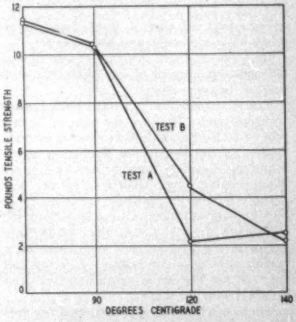


Figure 12. Ninety-six-day tests $2^1/_2$-mil paper tape in nonoxidizing liquid

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3. Loading Transformers by Copper Temperature, **Putman and Dann**. AIEE Transactions, volume 58, 1939, see 1939 annual Transactions index for page numbers.

4. **Staeger**, *Zeitsf. Angewandte Chem.*, volume 38, 1925, number 21, page 476.

5. **Frances and Garrett**, *Journal* Inst. Petroleum Tech., August 1938, page 435.

Discussion

V. M. Montsinger (General Electric Company, Pittsfield, Mass): I shall confine my remarks to the life tests on cellulose. The author has reported some very interesting results, the most important of which are (1) that if oxygen is not present cellulose will undergo very little deterioration either mechanically or electrically up to approximately 90 degrees centigrade or 95 degrees centigrade, and (2) that it retains a fair degree of its mechanical strength for many months even at 140 degrees centigrade. The peculiar thing about the results of Doctor Hill's tests is that after approximately 100 days there is apparently no further weakening of the insulation up to 650 days even at 140 degrees centigrade. This is difficult to understand, because we have been led to

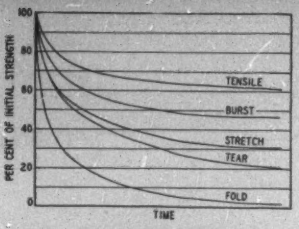

Figure 1. Mechanical deterioration of class A insulations as indicated by tensile, burst, stretch, tear, and folding strengths

believe that all class *A* insulations deteriorate with both time and temperature.

As I see it, there are two phases of this old question of aging of insulation that need further consideration.

The first question is, what causes insulations to age? Just to say that it is due mostly to oxidation does not go far enough. I recently showed, in my discussion of the paper on "Loading Transformers by Copper Temperature," by Messrs. Putman and Dann, the results of aging tests made in oil (1) with nitrogen atmosphere and (2) exposed to air, with practically no difference in the rate of deterioration, which was fairly rapid under both conditions. I do not feel that the mechanism of aging has ever been satisfactorily explained.

Then second, having determined the real mechanism of insulation deterioration, the next problem is to adapt the condition showing the least aging effects to apparatus under service conditions.

If, as shown in this paper, by merely keeping oxygen away from class *A* insulation its temperature can be increased to say 120 or 140 degrees centigrade, it might change materially our present practice of rating and loading apparatus. I do not believe that we are in a position yet to make any radical changes in temperature limits for class *A* insulations, and I believe that Doctor Hill will agree with me on this point. We need further confirmation of these new and very interesting results.

I note that the author's findings on two points agree with what I have found in the past, namely (1) that dielectric strength is no criterion by which to judge the degree of mechanical aging of insulation and (2) that the best method of measuring the amount of mechanical deterioration appears to be in comparing its tensile strength. My experience is that the effect of aging on mechanical strength is least upon the tensile strength. The order of magnitude of the effect ranges from tensile, to burst, to stretch, to tear, and is greatest for the folding test. This takes into account tests made on the principal kinds of transformer insulations including varnished and unvarnished papers, cloths, and pressboards. The wide variations obtained by these different methods of testing are shown in figure 1 which shows that folding tests indicate a very short life as compared with the life as indicated by tensile tests. It might appear that we should use the method which shows the greatest amount of deterioration—folding test. Experience, however, indicates that tensile strength comes more nearly representing the actual life of insulation as used in apparatus.

The question of the kind of test that should be used to determine the life of insulation in apparatus is only one of the many problems confronting an investigator. Generally speaking, no two investigators use the same methods and the results are so contradictory that no definite conclusions can be drawn.

The problem of investigating the aging of insulation is so important to the industry that I would like to suggest that the Institute set up the proper technical committee whose duty would be to correlate the work on the aging of insulation, and recommend standard methods of carrying on the work.

F. M. Clark (General Electric Company, Pittsfield, Mass.): The paper by Doctor Hill constitutes another important contribution to the problem of dielectric deterioration. Data in this field are rapidly accumulating and despite the wide differences noted at times, a clearer understanding is being obtained with respect to those factors which are important for the successful operation of commercial machines. Unfortunately, the problem of setting up temperature limits covering commercial operation of oil or cellulose or oil-treated insulation involves carefully controlled studies over long periods of time. I am, however, inclined to disagree with Doctor Hill when he states that data obtained in commercial equipment is somewhat more convincing than laboratory tests. Oxidation and pyrolysis tests are so affected by factors which are controlled only with difficulty even when known to be present that data obtained on large scale tests can be accepted as reliable only when supported and explained by accurately determined laboratory results. This is especially true for tests on mineral oil and cellulose.

Oxidation is, of course, an important factor in the successful operation of electrical apparatus and is an ever present threat which must be included in the life evaluation of organic insulation despite the varied methods which have been suggested for its elimination. But oxidation is not the only threat to the successful operation of cellulosic insulation at the higher temperatures of operation. This has been pointed out by Doctor Hill but I believe that the effect of nonoxidizing high-temperature exposure warrants greater consideration. Doctor Hill states that "heat alone will mechanically deteriorate the solid insulation at 100 degrees centigrade and above." This is true. In a paper which I presented before the Institute a few years ago entitled "The Pyrochemical Behavior of Cellulosic Insulation" (ELECTRICAL ENGINEERING, volume 54, October 1935, pages 1088–94) it was demonstrated that cellulosic insulation when exposed to high temperature bears the stamp of that exposure even though the high-temperature treatment be carried out under nonoxidizing conditions. The effects of this exposure fundamentally are chemical, and result in the chemical degradation of the cellulose, gas evolution, and deteriorated dielectric properties. These dielectric effects are especially noticeable for tests carried out on what are usually considered the highest type of dielectric materials such as cable and papers. I suggest that the reason the breakdown tests presented by Doctor Hill in figure 5 do not show such deterioration is that the breakdown examined is a function of the preceding corona discharge. This corona discharge usually occurs in tests such as those cited by Doctor Hill and its effect very largely determines the breakdown value, masking other factors which may be present.

Doctor Hill differentiates between the thermal aging of insulation at temperatures above 100 degrees centigrade and the oxidation aging of cellulose below 100 degrees centigrade. The part played by mineral oil in the aging of cellulosic insulation at 100 degrees centigrade and below has been a debatable question. Doctor Hill apparently agrees with those who claim that acids formed in the oil as a result of oxidation are factors contributing to the mechanical weakening of the insulation. Doctor Hill goes further and suggests that the "deterioration takes place on the untreated cellulose even before serious acidity is developed in the oil, due, we believe, to the effect of oxygen carried to the cellulose by the oil itself through the formation of peroxide." This is important if true. From the data submitted by Doctor Hill it is impossible to decide the validity of this assertion. That it may be true is indicated by a comparison of figures 6 and 12. Figure 12 concerns itself with paper tape immersed in a nonoxidizing and noninflammable liquid in a sealed container in contact with air, and figure 6 describes tests on fullerboard immersed in oil presumably with free exposure to air. However, Doctor Hill presents no data concerning tests on paper tape under oil similar to the tests described in figure 12. Presumably the amount of air in the sealed container of figure 12 constituted about 10 per cent to 15 per cent of the total volume of the container so that enough oxygen was present to give some oxidation effects if oxidation were an important factor with cellulose immersed in noninflammable type of insulating liquid. In such a material peroxide effects are definitely absent. The oxygen cannot be used up by the oxidation of the liquid which is chemically inert. Therefore, the effects of cellulose oxidation can be obtained only by the migration of the oxygen through the inert noninflammable liquid. This might be expected to retard the mechanical deterioration due to oxidation. Figure 12 confirms this expectation and shows that the paper tape under the noninflammable liquid shows no substantial change in mechanical strength after 96 days at 95 degrees centigrade. Figure 6 shows that the mechanical strength of the fullerboard in oil fell about 75 per cent during the same interval. These data may well indicate that the noninflammable liquids because of their chemical stability and nonoxidation characteristics effectively reduce the tendency of cellulosic insulation to deteriorate mechanically at temperatures of operation below 100 degrees centigrade where oxygen-free atmospheres have been shown by Doctor Hill to be of value for mineral-oil-immersed insulation.

There can be but little doubt that oil acids must not be ignored in the evaluation of the mechanical characteristics of oil-immersed cellulose. Mineral oil when oxidized pro-

duces oil-soluble products which are capable of absorbing alkali. These materials are usually classed as oil acids. Total oil acidity as illustrated by Doctor Hill in figure 1 does not appear to me to be of major importance. What does appear of importance is the formation of water-soluble organic acids. These are present to an extent dependent on the type of oil base and on its refining treatment. With the highly refined (white) oils the water-soluble corrosive acids predominate. With a carefully selected oil whose refining treatment has been properly supervised these water-soluble corrosive acids are present in only negligible amounts. The variation in the formation of these water-soluble corrosive acids may account for the wide differences which are at times reported in the literature covering the mechanical aging of oil-immersed cellulose.

Acetic acid is one of the corrosive organic acids evolved by the oxidation of highly refined white oils. It is this type of acid which is formed by the exposure of cellulose to high temperatures even in the absence of oxygen. Cellulose evolves a variety of degradation products whose formation begins slowly at relatively low temperature. These are in general poor dielectrics and of strong chemical reactivity. The presence of these products retained in contact with the cellulose accelerates further deterioration, a weakening in mechanical strength, and a decrease in dielectric efficiency. For high-temperature operation these effects appear to predominate. For lower temperature operation (80 degrees centigrade to 90 degrees centigrade) the most important factor affecting the mechanical life of cellulose based on the data of Doctor Hill appears to be one of oxidation. This apparently can be reduced and possibly eliminated by the use of nitrogen atmospheres to replace air or oxygen or by the use of a nonoxidizing, noninflammable liquid.

H. V. Putman (Westinghouse Electric and Manufacturing Company, Sharon, Pa.): The thing which strikes me as most significant about Doctor Hill's results is the extremely wide range in the effectiveness with which the oil and insulation are protected against deterioration in different types of transformers. Using Doctor Hill's data, Mr. Vogel has shown that the life of the oil in transformers under nitrogen may be 50 times as long as with open-air breathing.

If we examine Doctor Hill's figures 7 and 10, we see that yellow treated tape in oil under air deteriorates as much in a month as it does in oil under nitrogen in two years.

And yet our present standards establish the same maximum temperature limits and short-time overload capacities for all types of transformers. Obviously those having effective means for protection of oil and insulation can stand higher temperatures and more severe overloads than those not having such means.

I am not prepared to say that we should increase the standard temperature rise of 55 degrees centigrade for transformers. Perhaps we should outlaw open-air breathing. Mr. Hellmund has pointed out that perhaps the reason European manufacturers are successful with a higher temperature rise is because all their transformers large and small are protected by some kind of a conservator.

It does appear in order to suggest that the AIEE transformer subcommittee undertake a review of our present rules affecting maximum temperatures and overloads with a view to bringing them into harmony with the engineering facts established in Doctor Hill's paper.

H. C. Louis (Consolidated Gas Electric Light and Power Company of Baltimore, Md.): The paper by C. F. Hill, presents the results of some very elaborate laboratory tests showing the effects of temperature and aging on the electrical and mechanical qualities of insulation. The results add much information useful in the design, rating, and operation of electrical apparatus as related to insulation. They contribute fundamental data of value in the important and much debated subject under consideration, the allowable temperature limits of insulation, and whether those in existing standards should be modified.

We note with particular interest that in these carefully controlled laboratory tests, in some cases of definitely marked deterioration of mechanical characteristics of insulation the electrical characteristics did not deteriorate correspondingly, and continued to be apparently fairly good. This checks with a condition sometimes experienced in actual operation in cases where apparatus seems to be able to operate satisfactorily and reveals no weaknesses on electrical tests, although inspection may show the insulation to be in very questionable mechanical condition.

This question of determining the condition and expected additional life of insulation of used apparatus is one of practical operating concern, involving reliability of service and economics. Development and investigations of field methods for checking the condition of insulation by special tests and inspections should continue to be encouraged.

The correlation of the data from the paper under discussion with others relating to the same subject, as recommended by Mr. Montsinger, should therefore serve not only the primary purpose of the question of temperature limits and ratings, but should also contribute useful information in the problem of judging by tests and inspection the condition of insulation of apparatus in use, and the possible additional life of same.

R. E. Hellmund (Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa.): As already briefly stated by Mr. Putman, the data presented by Doctor Hill in his paper and other calculations given by Mr. Vogel in his written discussion seem to explain a controversy of long standing with the International Electrotechnical Commission regarding permissible temperature ratings of transformers. The European countries wish to standardize on temperature-rises somewhat higher than those considered safe by the American representatives. The early assumption that the European practice might be less conservative can hardly be considered correct, because the scarcity and high price of oil in Europe make it necessary for them to be more economical in the use of oil than it is in this country. A slight difference in climatic conditions might, of course, have some influence on their service experience. However, it seems that on account of the greater need for preservation of materials, expansion tanks have been used in Europe to a great extent for transformers of even the smallest sizes. In contrast to this, in this country the distribution transformer has been used until fairly recently without such tanks and with the surface of the oil freely exposed to air and oxygen. It seems from these newly available data that they may have obtained service results as good as or even better than those we have obtained in the past, even though their rating standards include higher temperature-rises. Although it may be premature for us to change our rating standards at this time, it seems advisable in our international contacts to recognize these differences and to make some concessions in connection with the work of the IEC.

Herman Halperin (Commonwealth Edison Company, Chicago, Ill.): This paper adds considerably to our knowledge of oil-impregnated insulation. The effects of temperature are shown to vary appreciably depending on the conditions of test and test procedure. Nevertheless the paper brings out again the point that when class *A* insulation is operated continuously at temperatures of 90 or 95 degrees centigrade or higher the rate of deterioration increases fairly rapidly. In other words, a short life will obtain when the insulation is operated continuously at the present "hot spot" temperature limit of 105 degrees centigrade of the AIEE rules.

Doctor Hill's data show that when testing paper under oil which is exposed to air the oxidation products of the oil will affect the strength of the paper. This test procedure is satisfactory, I presume, if it simulates the service condition. For some equipment, such as capacitors and cable, the oxygen, however, is pretty well removed from the insulation in manufacture and kept so during operation.

In connection with his figure 12 showing the decrease in tensile strength with temperature, it seems to me that the criterion of tearing strength is most valuable to use in such tests. This test gives a large range in results of tests of deteriorated material and the results seem to be most consistent. Probably the folding endurance test, as developed in the research at Massachusetts Institute of Technology about 15 years ago, is too much influenced by moisture, both free and combined, to be reliable.

F. J. Vogel (Westinghouse Electric and Manufacturing Company, Sharon, Pa.): Doctor Hill's paper should be of considerable interest to all users of transformers because it gives basic data which can be used to estimate the life of oil and insulation under various conditions of operation. It shows how extremely important it is to protect transformer oil against oxidation, particularly when the oil is operated at high temperatures. It shows that even small amounts of oxygen continuously admitted to the transformer tank over long periods of

time can seriously shorten the life of the transformer oil. Consequently, it is important that gasketing be done in the best possible and most permanent manner. A positive pressure of nitrogen ranging from one-half pound upward is further assurance against the possibility of oxygen or air entering the transformer tank.

Doctor Hill has shown that deterioration of insulation is a function both of temperature and oxidation, while the deterioration of the oil is primarily a function of oxidation, which, fortunately, can be eliminated almost completely by the use of nitrogen above the oil level.

For example, Doctor Hill shows that 0.4 cubic foot of oxygen per gallon of oil will produce an acidity of one milligram of KOH. Sludging is usually considered to begin when the acidity reaches 0.5 milligram of KOH, which would correspond to 0.2 cubic foot of oxygen per gallon of oil. For comparative purposes it is interesting to calculate the time required to produce this amount of acidity in the oil under various conditions of breathing in a typical transformer. As an example, we have used a 2,500-kva unit containing 680 gallons of oil, having an 88-inch oil level, with 10-inch gas space and 16.4 square feet of oil surface. This transformer would require 136 cubic feet of oxygen to produce 0.5 milligram of KOH acidity in the oil. We know from experience that a transformer of this size would use from 1 to $1^1/_3$ cylinders of nitrogen per year, or, roughly, 275 cubic feet. This gas is purchased under specification limiting impurities to 0.5 per cent, and for the purposes of calculation it may be assumed that the impurities are entirely oxygen—or 1.37 cubic feet. It may further be assumed, for the purpose of calculation, that the transformer is opened up once per year for inspection, and when closed up the gas space is blown out to five-per cent oxygen concentration, which would leave an additional 0.68 cubic foot of oxygen in the gas space annually. The total amount of oxygen in the gas space available for oxidation of the oil would therefore be 2.05 cubic feet per year, which would require 67 years before any sludging would appear—and most important, this would not be dependent upon the temperature of the oil.

If the transformer tank were bolted up tight with no breathing but were opened once a year for inspection and the gas space filled with air upon closure, 50 years would be required for sludge to appear.

In making calculations for various types of breathers, it is necessary to assume some daily load cycle and also to establish an average oil temperature. Seventy-five degrees has been assumed for the oil temperature with a temperature fluctuation of 20 degrees daily. Under this condition the transformer would breathe in approximately 612 cubic feet of air per year containing approximately 123 cubic feet of oxygen.

Let us assume, at this point, that the transformer is equipped with a single breather which takes in air when the transformer cools and breathes it out during the heating-up part of the cycle. Very approximately we can say that the amount of air breathed in equals the amount of air breathed out. This is not quite true due to the fact that there is some gas absorption in the oil. More exactly, we can say that the amount of oxygen breathed in is equal to the amount of oxygen breathed out plus the amount of oxygen absorbed by oxidation in the oil. To fulfill this latter equation, it is necessary to assume an average oxygen concentration and refer to figure 4 of Doctor Hill's paper to see if the amount absorbed plus the amount breathed out will equal that taken in. Assuming approximately $5^1/_2$-per cent average oxygen concentration, 34 cubic feet of oxygen would be discharged in the out breathing. From figure 4 the rate of oxygen absorbed per square foot of oil surface per year would be 0.00062. At this same concentration the amount absorbed in a year would be $0.00062 \times 16.4 \times 24 \times 365$ or 89 cubic feet. The conditions of the equation regarding oxygen are fulfilled, since 123 cubic feet breathed in equals 34 cubic feet breathed out plus 89 cubic feet absorbed. Since 136 cubic feet of oxygen are required for the oil to reach 0.5 milligram of KOH acidity, and 89 cubic feet would be absorbed annually under the conditions described, it would only take about a year or a year and a half for the oil in a transformer with a single breather to reach a condition where it would begin to sludge.

Similar methods of calculation may be used for other breather arrangements.

Occasionally double breathers are used which provide a constant circulation of air through the gas space above the transformer. This arrangement is quite advantageous from the point of view of preventing moisture condensation on the cover. However, it does provide a high oxygen concentration above the gas space with consequent short oil life. Assuming the same average oil temperature (75 degrees centigrade) and only 16 per cent oxygen concentration (which seems conservative) the oil in the transformer should require only 0.6 of a year to reach 0.5 milligram of KOH acidity.

The case of the simple expansion tank can be calculated with less assurance from the data presented by Doctor Hill because the oil in the conservator tank might be somewhat more quiescent than in the main tank and therefore less accessible to oxidation. Also the temperature of the conservator tank varies widely depending on the type of connection to the main tank. However, in an actual heat run the temperature of the oil in the conservator was 58 degrees, when the oil in the main transformer was 75 degrees. Assuming the same daily load cycle as previously and applying the calculation to the surface of the oil in the conservator, which was $7^1/_3$ square feet, it was found that of the 123 cubic feet of oxygen breathed in, 85 were breathed out and 38 absorbed, with the result that 3.6 years would be required before sludging would appear. With types of construction which tend to reduce the oil circulation and the temperature of the oil in the conservator, the time might be considerably longer—perhaps even 6 or 7 years.

The merit of nitrogen protection or tightly sealed tanks is apparent from the above calculations from the standpoint of oil deterioration.

In interpreting the insulation deterioration results which Doctor Hill presents, in terms of actual transformer construction, it should be recognized that the insulation in the transformer, which is subjected to appreciable mechanical stress, is actually at the oil temperature rather than at the copper temperature. In fact, it is only the insulation covering the copper conductor itself which reaches the maximum copper temperature, and here a deterioration in tensile strength of 50 to 75 per cent is probably not serious once the insulation is in place in the transformer. Doctor Hill's data on insulation deterioration in nitrogen indicate that the deterioration due to temperature takes place relatively quickly—that is, in 100 to 150 days. After that there appears to be little further deterioration, and the loss in tensile strength even at temperatures as high as 120 degrees would not appear to be a serious matter. This is particularly true since most of the insulation is used in compression rather than in tension, and the decrease in tensile strength is probably not accompanied by a commensurate decrease in compression strength.

It can be concluded from Doctor Hill's data that the maximum safe temperature limits, particularly for short periods of time, can be considerably higher in types of transformers having effective protection of the oil and insulation against oxidation.

The proposed recommendations of the American Standards Association for short-time overload capacity of transformers appear to be extremely conservative when applied to transformers having protection against oxidation. With such transformers, continuous operation at rated load, 55 degrees rise, and at 40 degrees ambient, is possible without measurable deterioration.

Charles F. Hill: Mr. Putman and Mr. Hellmund have called attention to European practice of higher temperatures in distribution transformers than permitted in America, and the fact that my results explain and justify the argument for this European practice. As Mr. Putman points out, it is illogical to use devices to keep out oxygen and then limit the transformer to the same temperature as a free-breathing unit.

Mr. Montsinger points out the apparent flattening off of the deterioration rate of cellulose in my results, after a relatively few months. The flat part of the curve could have been given a slight slope and still fit the data, but the rapid initial effects were rather striking. I suspect some initial oxidation due to residual oxygen in the oil with more frequent opening of the apparatus could have distorted the early results in this respect. The important point is that the mechanical deterioration at the end of two years is not nearly so great as normally expected. The shape of the curves points out the difference in conclusions to be reached, depending upon the length of the life test as emphasized by Smith and Scott in their paper.

As to the rate of deterioration and the "8 degree" rule or "10 degree" rule now under consideration, I believe this is too conservative for this case, but this subject is analyzed in more detail in my discussion of the paper by Smith and Scott (page 444).

My results emphasize again the accepted conclusion that deterioration of the organic materials (solids) is primarily mechanical and not electrical. The choice of tests to measure this deterioration is somewhat a problem, but we have concluded tensile tests are most dependable.

Referring to Mr. Halperin's comment, it is true as he points out that these results as well as previous experiments and experience show a critical temperature for cellulose around 100 degrees centigrade, but to get 100 per cent deterioration, even at higher temperatures, requires a long time. Our results also show, as he mentions, that oxygen has a very marked effect when both high temperature and oxygen are applied to oil-immersed cellulose.

Mr. Halperin has also raised the question of type of test and suggested a tearing test. I believe embrittlement measurements for this case would be more in order. We have had some degree of success with these.

I agree in general with F. M. Clark's statements concerning the relative value of controlled laboratory tests and "commercial" tests. The data on oils in my paper, figures 2 to 4, inclusive, are more nearly laboratory experiments than commercial in that conditions were rather closely controlled.

It is not clear to me just what Mr. Clark's explanation of the apparent lack of electrical deterioration may be. The oil-soaked fullerboard remains good electrically, as also did the oil in the inert gas tests.

Mr. Clark has also discussed the mechanisms by which oil or oxidized oil deteriorates cellulose. It was not the intention to add data to the paper to prove a theory of these mechanisms, but from other results we do believe peroxide stages of oil oxidation are a serious factor. Concerning the ability of oil to carry oxygen to cellulose, we believe that is generally accepted and it is probable that in the presence of an oxygen atmosphere, the nonoxidizing fireproof liquids may show less effect upon cellulose at 80–85 degrees centigrade than does oil. As Mr. Clark states, also, the lighter water-soluble acids formed in oil oxidation are the more active.

Our experiments were so selected as to show the deterioration effects and their degree within the various temperature ranges and so far as I can see from Mr. Clark's discussion, he agrees in a general way with our results. We recognize, of course, that some of the mechanisms of deterioration are not as yet explained.

Mr. Vogel has used the oil data to determine the life of a transformer oil under various conditions of operation, that is, under various amounts of available oxygen for oil deterioration. I believe our results will be of considerable value to the user of transformers in determining what he should demand in the way of protection against oil oxidation.

The data on oil and cellulose deterioration both should be of value to the operating engineer in determining what to do with transformers in service. Mr. Louis points out in his discussion that the operating engineer needs such information. I believe, as Mr. Louis suggests, that the data given will be found of considerable value. No doubt more experiments may be necessary to give a complete and accurate picture and I hope operating engineers will attempt to utilize the data enough to evaluate the results.

So far as temperature limits and standards are concerned, the paper raises some very important questions, but these have been pointed out by Mr. Putman and need no further discussion.

Capacitors and Automatic Boosters for Economical Correction of Voltage on Distribution Circuits

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Synopsis: Analysis of operating characteristics shows that fixed shunt capacitors may be used to provide voltage correction up to approximately three per cent on a typical four-kv distribution circuit. Installation of capacitors up to this limit, or to unity power factor on the feeder if that occurs with less capacity, generally gives voltage improvement at minimum cost.

Additional correction can be secured with a set of automatic voltage boosters beyond the shunt capacitors, except that single-phase taps from near the feeding point should have the other phases extended first to secure lowest cost. This procedure requires only three different devices, a 30-kva single-phase capacitor, a 90- to 180-kva three-phase capacitor, and a 5-kva automatic booster with two 1.33-per-cent steps, to secure appreciable economies in distribution cost.

RECENT years have seen the introduction and promotion of three additional types of equipment to correct abnormal voltage conditions on distribution circuits, namely: (1) the automatic voltage booster, (2) the shunt capacitor, and (3) the series capacitor. Each one functions in a different way to regulate voltage, and has certain other effects, which make direct comparison of price an unfair test of true economic value. This paper undertakes to compare them as they might be applied to the system of the Duquesne Light Company, subject to the voltage limitations and other conditions of that system, and to ascertain which device or combination of devices should be used to maintain the voltage at consumers' service switches within the prescribed limits. Inasmuch as the Duquesne Light system is generally similar to those operating elsewhere in areas of similar population density, it seems probable that the conclusions will be fairly representative.

The typical circuit is three-phase, four-wire, four-kv, regulated at the substation by single-phase induction regulators. By means of line drop compensators, the regulators are made to correct for voltage drop in the main feeder, and it is assumed that they regulate the primary voltage directly at the first tap or transformer (called the "feeding point"). This feeding-point voltage normally varies between 102.0 per cent at light load and 104.0 per cent at peak load, always with a tolerance of ± 1.0 per cent for the margin between "raise" and "lower" in the contact-making voltmeters controlling the regulators. These values have been established to give as good voltage as possible as much of the time as possible to as many consumers as possible without sacrificing the economic advantage of raising the feeding-point voltage close to the 105.0 per cent limit during peaked load. With voltage drops at peak load of up to 3.0 per cent in the primary system, 2.5 per cent in distribution transformers, 2.0 per cent in secondaries, and 0.5 per cent in services, the delivered voltages will range from nearly 104.0 ± 1.0 per cent for a consumer fed by a very lightly loaded transformer at the feeding point down to 96.0 ± 1.0 per cent for a secondary consumer at some distance from a heavily-loaded transformer at the end of the primary. This circuit is discussed more fully in the paper "Automatic Boosters on Distribution Circuits"[3] from which figure 1 is taken.

Attempts to benefit by the assumption that consumers near the feeding point always have at least the voltage drop of a 50-per-cent-loaded transformer below the primary voltage at the feeding point during the circuit heavy-load periods, accordingly raising the feeding-point voltage an extra 1.0 per cent to 105.0 ± 1.0 per cent, have not been successful on the Duquesne Light system and have been abandoned because of complaints. The conditions shown in figure 1 represent the maximum voltage drops with which service voltage can be maintained within the established limits, and are typical of a 1,500-kva four-kv open-wire circuit feeding

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3. For all numbered references, see list at end of paper.

three or four square miles of fairly uniform suburban load with an extreme length from the feeding point to the end of the longest primary branch of around two miles.

But load increases both in density and in area, and the tendency is to extend the long branches and to carry more and more load on the circuit. Immediately the voltage drop increases, and before long it becomes necessary to provide some means to bring the voltage back within the established limits. When the circuit has ample current-carrying capacity, an advanced feeding point is established nearer the center of load and a back feed is built to serve load along the feeder. Sometimes that does not suffice, and a new feeder or substation may be built to share the load. Both methods ordinarily are expensive, and frequently can be delayed for a number of years by the use of voltage corrective devices,[2] sometimes with considerable savings in annual cost.

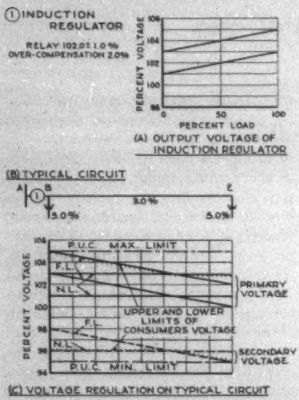

Figure 1. Voltage regulation of typical distribution feeder by induction regulators at substation

Automatic Voltage Boosters

About six years ago leading power companies started to use automatic voltage boosters to correct low voltage on long circuits, particularly for rural districts where rather coarse voltage steps were adequate. The size of step is directly reflected in the output voltage, however, and the earlier paper[3] indicated a two-step booster having 2.66 per cent total range as the most economical design for operation within a total primary voltage variation of 5 per cent. The effect of such a booster is shown in figure 2; with a primary voltage drop 89 per cent greater than could be permitted in the original circuit, figure 1*B*, the voltage delivered to consumers is held within the same limits by means of the automatic boosters. Analysis showed that automatic boosters were economically applicable where satisfactory regulation could be secured without boosters only by extensive installation of 1/0 or 4/0 conductors on the three-phase portion of the circuit.

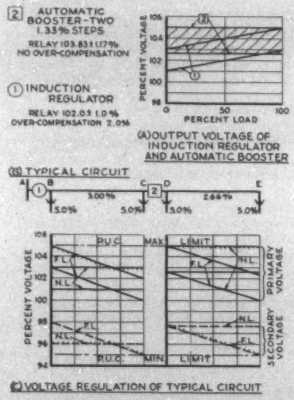

Figure 2. Voltage regulation of typical distribution feeder by induction regulators at substation and automatic boosters on poles

Shunt Capacitors

In 1930 a number of four-kv shunt capacitors were installed by the Duquesne Light Company on circuits in industrial areas to correct for the low power factor then existing. The depression which came even before these installations were complete had the triple effect of reducing the industrial load, making industrial consumers more anxious to benefit by allowances for good power factor, and retarding the expenditures required to serve adequately the continually growing domestic load particularly in areas only recently developed. As early as 1932, capacitors were being moved from industrial circuits to suburban areas to reduce the voltage drop in overextended circuits.

The voltage corrective effect of the shunt capacitor is due to the leading reactive current which, flowing through the circuit from the regulated source at the feeding point to the capacitors out in the load area, produces a rise in voltage equal to the product of the capacitative current and the line reactance. This voltage correction varies with the distance, from zero at the feeding point to full value at the capacitor. Ordinarily the capacitor is permanently in service, and so raises the voltage by the same amount at light load on the circuit as at full load.[4]

The maximum correction which can be secured by use of fixed shunt capacitors can be determined very readily from charts of voltage at the proposed location, the limit being that capacity which raises the voltage during light-load periods to the upper limit of 105.0 per cent. Usually the light-load voltage along a circuit is practically constant along the entire length, substantially equal to the contact-making voltmeter setting of 102.0 ± 1.0 per cent. With these voltage conditions only 2.0 per cent voltage correction can be secured by means of shunt capacitors. More correction can be used, however, by balancing the voltmeter at 101.0 per cent and increasing the line drop compensation, which would permit as much as 3.0 per cent correction by means of shunt capacitors.*

It is seldom possible or desirable to locate the capacitors directly at the end of the circuit, as this would give the maximum voltage correction at one point only and less correction at the ends of other branches of the circuit where full correction is as much needed. Generally they are installed at some such point as the end of the three-phase circuit or a branch point of the three-phase circuit, in either case leaving some drop in the primary laterals beyond the capacitor to the last transformers. A circuit embodying these characteristics is shown as figure 3, which indicates that full advantage has been taken of the permissible variation in voltage and that it is not feasible to correct the primary voltage more than 3.0 per cent with fixed shunt capacitors.

If more than 3.0 per cent correction is desired, then additional capacitors can be installed with a switch controlled by a contact-making voltmeter to cut them into service when the voltage drops below the desired level. With voltage limits at the point of installation of 101.0 per cent to 105.0 per cent, automatic voltage-controlled shunt capacitors could

* Usually the light-load voltage can be lowered somewhat more, which would permit some additional voltage correction by shunt capacitors. It must be borne in mind, however, that a circuit having good phase balance at peak load may have appreciable unbalance at light load, and that this unbalance added to the voltage rise caused by fixed shunt capacitors might cause excessively high voltage on the lightest loaded phase during light load. Accordingly, the limit to voltage correction by fixed capacitors has been set at three per cent.

be applied to give up to 3.0 per cent additional voltage correction. A circuit with both fixed and automatic capacitors could have a total of 9.0 per cent primary drop, of which 6.0 per cent would be corrected by the capacitors. The automatic capacitors would require individual phase control to compensate for neutral shift, and might as well be single-phase installations. Voltage regulation on a typical circuit with both fixed and automatic shunt capacitors is shown in figure 4.

The shunt capacitor raises voltage by drawing capacitative current. Inasmuch as the typical distribution feeder has a peak-load power factor approximately 90 per cent lagging, the shunt capacitor tends not only to improve voltage but also to improve the circuit power factor. This results in lower kilovolt-ampere demand for the same peak load, and releases carrying capacity in the circuit and in all of the supply system. On systems having low power factor this improvement in power factor is most desirable; the system capacity released is available to

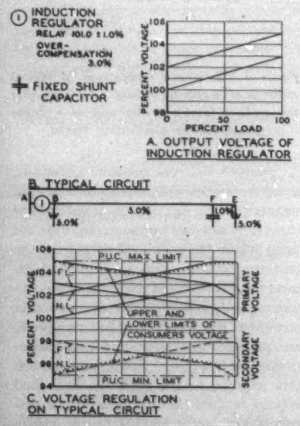

Figure 3. Voltage regulation of typical distribution feeder by induction regulators at substation and fixed shunt capacitors on poles

carry increased load and has the same value per kilovolt-ampere as an addition to the system.[5] When the system power factor already runs higher than the rating of the generators, then the only value creditable to improved power factor is the capacity released in main feeder, substation, and transmission system. The latter is true of the present analysis, and a value of $50.00 per kilovolt-ampere has been assumed for the reduction in demand. With the present price of 2,400-volt capacitors running under $8.00 per capacitative kilovolt-ampere, it is evident that credit for reduction in peak demand might pay a large portion of the cost of capacitors, leaving a rather small charge for the voltage improvement for which they are installed.

For example, a circuit carrying 1,500 kva at 90 per cent power factor might require the installation of 360 kva of shunt capacitors for voltage correction. The capacitors would raise the circuit power factor to 98 per cent and reduce the circuit demand measured at the substation from 1,500 kva to 1,385 kva. This reduction in demand of 115 kva, evaluated at $5,750, is secured from shunt capacitors having a purchase price of approximately $2,700. With the cost of the capacitors more than covered by credit for reduction in demand, the voltage correction is secured free of charge.

Series Capacitors

Capacitors of proper rating installed in series in a circuit also tend to reduce the voltage drop.[1] The effect is computed readily as the product of the capacitative reactance and the reactive component of

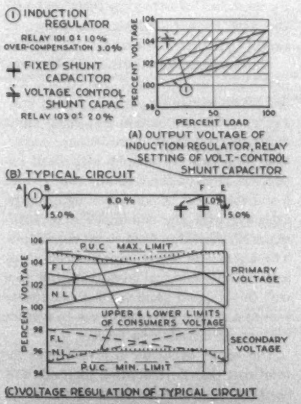

Figure 4. Voltage regulation of typical distribution feeder by induction regulators at substation and shunt capacitors, partially controlled by voltage, on poles

the current flowing through the capacitor. Installed at the point where the primary voltage reaches the lower limit, 101.0 ± 1.0 per cent, it should have such an impedance as would, with the maximum load current flowing through it, raise the voltage 3.0 per cent, or to 104.0 ± 1.0 per cent. As the load decreases, the power factor drops, and the out-of-phase component tends to decrease but little. The voltage boost of the series capacitor, therefore, is nearly as great during light load as during heavy load, and it is necessary to check several different load conditions to avoid excessively high voltages on the output side. For present purposes, however, it is assumed that the capacitor selected to give 3.0 per cent rise at peak load is satisfactory. The voltage regulation of the typical circuit with this series capacitor is shown in figure 5.

Economic Comparison

There are now five different methods for correcting the voltage regulation of a circuit, namely:

1. Rebuild for greater current-carrying capacity, by changing single-phase to three-phase, replacing present conductors with larger conductors, or building a new circuit to divide the load.

2. Extend the feeding point farther into the load area, back feeding the load along the main feeder and regulating voltage at the new feeding point by increased use of the feeder regulators at the substation.

3. Correct for excessive voltage drop in the existing circuit by installing automatic voltage boosters at the proper points.

4. Correct for excessive voltage drop in the existing circuit by installing shunt capacitors near the ends of the branches. Where fixed capacitors alone do not suffice, additional correction can be secured by means of voltage-controlled automatic capacitors.

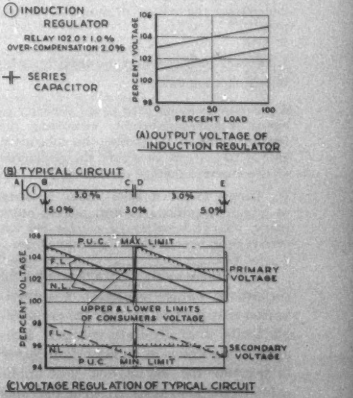

Figure 5. Voltage regulation of typical distribution feeder by induction regulators at substation and series capacitors on poles

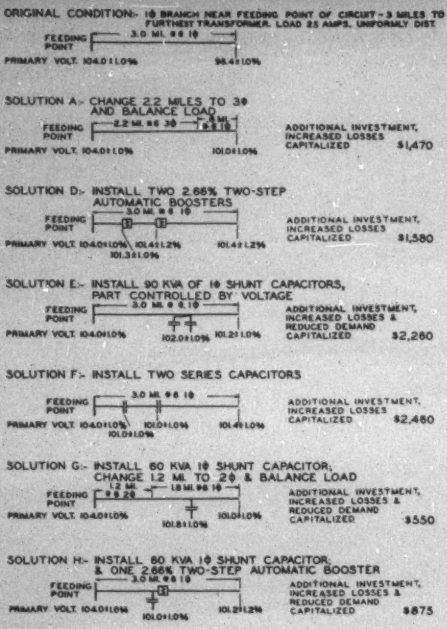
ORIGINAL CONDITION:- 1Ø BRANCH NEAR FEEDING POINT OF CIRCUIT - 3 MILES TO FURTHEST TRANSFORMER. LOAD 25 AMPS. UNIFORMLY DIST.
FEEDING POINT
3.0 MI. #6 1Ø
PRIMARY VOLT. 104.0 ± 1.0%
98.4 ± 1.0%
SOLUTION A:- CHANGE 2.2 MILES TO 3Ø AND BALANCE LOAD
2.2 MI. #6 3Ø
.8 MI. #6 1Ø
ADDITIONAL INVESTMENT, INCREASED LOSSES CAPITALIZED $1,470
PRIMARY VOLT. 104.0 ± 1.0%
101.0 ± 1.0%
SOLUTION D:- INSTALL TWO 2.66% TWO-STEP AUTOMATIC BOOSTERS
3.0 MI. # 6 1Ø
ADDITIONAL INVESTMENT, INCREASED LOSSES CAPITALIZED $1,580
PRIMARY VOLT. 104.0 ± 1.0%
101.4 ± 1.2%
101.3 ± 1.0%
101.4 ± 1.2%
SOLUTION E:- INSTALL 90 KVA OF 1Ø SHUNT CAPACITORS, PART CONTROLLED BY VOLTAGE
3.0 MI. # 6 1Ø
ADDITIONAL INVESTMENT, INCREASED LOSSES & REDUCED DEMAND CAPITALIZED $2,260
PRIMARY VOLT. 104.0 ± 1.0%
102.0 ± 1.0%
101.2 ± 1.0%
SOLUTION F:- INSTALL TWO SERIES CAPACITORS
3.0 MI. #6 1Ø
ADDITIONAL INVESTMENT, INCREASED LOSSES CAPITALIZED $2,460
PRIMARY VOLT. 104.0 ± 1.0%
101.0 ± 1.0%
101.0 ± 1.0%
101.4 ± 1.0%
SOLUTION G:- INSTALL 60 KVA 1Ø SHUNT CAPACITOR; CHANGE 1.2 MI. TO 2Ø & BALANCE LOAD
1.2 MI. #6 2Ø
1.8 MI. #6 1Ø
ADDITIONAL INVESTMENT, INCREASED LOSSES & REDUCED DEMAND CAPITALIZED $550
PRIMARY VOLT. 104.0 ± 1.0%
101.8 ± 1.0%
101.0 ± 1.0%
SOLUTION H:- INSTALL 60 KVA 1Ø SHUNT CAPACITOR & ONE 2.66% TWO-STEP AUTOMATIC BOOSTER
3.0 MI. #6 1Ø
ADDITIONAL INVESTMENT, INCREASED LOSSES & REDUCED DEMAND CAPITALIZED $875
PRIMARY VOLT. 104.0 ± 1.0%
101.0 ± 1.0%
101.2 ± 1.2%

Figure 6. Economic comparison of several methods of improving voltage on a three-mile single-phase branch at the feeding point of a three-phase four-kv distribution feeder

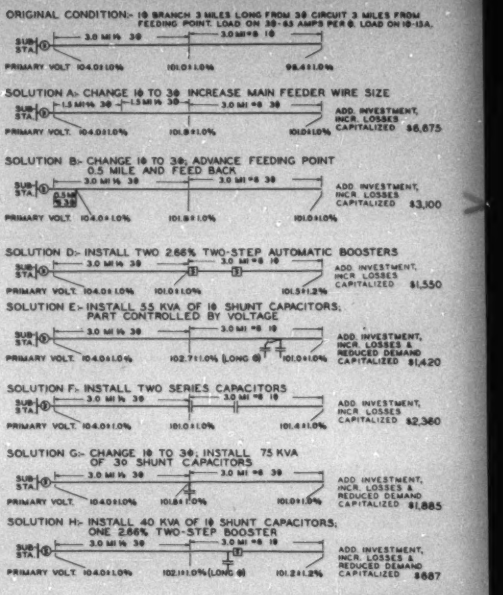
ORIGINAL CONDITION:- 1Ø BRANCH 3 MILES LONG FROM 3Ø CIRCUIT 3 MILES FROM FEEDING POINT. LOAD ON 3Ø-6.5 AMPS PER Ø. LOAD ON 1Ø-13A.
SUB STA.
3.0 MI #4 3Ø
3.0 MI #8 1Ø
PRIMARY VOLT. 104.0 ± 1.0%
101.0 ± 1.0%
98.4 ± 1.0%
SOLUTION A:- CHANGE 1Ø TO 3Ø INCREASE MAIN FEEDER WIRE SIZE
1.5 MI #4 3Ø
1.5 MI #6 3Ø
3.0 MI #8 3Ø
ADD. INVESTMENT, INCR. LOSSES CAPITALIZED $6,675
PRIMARY VOLT. 104.0 ± 1.0%
101.8 ± 1.0%
101.0 ± 1.0%
SOLUTION B:- CHANGE 1Ø TO 3Ø; ADVANCE FEEDING POINT 0.5 MILE AND FEED BACK
3.0 MI #4 3Ø
0.5 MI #4 3Ø
3.0 MI #8 3Ø
ADD. INVESTMENT, INCR. LOSSES CAPITALIZED $3,100
PRIMARY VOLT. 104.0 ± 1.0%
101.8 ± 1.0%
101.0 ± 1.0%
SOLUTION D:- INSTALL TWO 2.66% TWO-STEP AUTOMATIC BOOSTERS
3.0 MI #4 3Ø
3.0 MI #8 1Ø
ADD. INVESTMENT, INCR. LOSSES CAPITALIZED $1,550
PRIMARY VOLT. 104.0 ± 1.0%
101.0 ± 1.0%
101.5 ± 1.2%
SOLUTION E:- INSTALL 55 KVA OF 1Ø SHUNT CAPACITORS, PART CONTROLLED BY VOLTAGE
3.0 MI #4 3Ø
3.0 MI #8 1Ø
ADD. INVESTMENT, INCR. LOSSES & REDUCED DEMAND CAPITALIZED $1,420
PRIMARY VOLT. 104.0 ± 1.0%
102.7 ± 1.0% (LONG Ø)
101.0 ± 1.0%
SOLUTION F:- INSTALL TWO SERIES CAPACITORS
3.0 MI #4 3Ø
3.0 MI #8 1Ø
ADD. INVESTMENT, INCR. LOSSES CAPITALIZED $2,360
PRIMARY VOLT. 104.0 ± 1.0%
101.0 ± 1.0%
101.4 ± 1.0%
SOLUTION G:- CHANGE 1Ø TO 3Ø; INSTALL 75 KVA OF 3Ø SHUNT CAPACITORS
3.0 MI #4 3Ø
3.0 MI #8 3Ø
ADD. INVESTMENT, INCR. LOSSES & REDUCED DEMAND CAPITALIZED $1,885
PRIMARY VOLT. 104.0 ± 1.0%
101.8 ± 1.0%
101.0 ± 1.0%
SOLUTION H:- INSTALL 40 KVA OF 1Ø SHUNT CAPACITORS; ONE 2.66% TWO-STEP BOOSTER
3.0 MI #4 3Ø
3.0 MI #8 1Ø
ADD. INVESTMENT, INCR. LOSSES & REDUCED DEMAND CAPITALIZED $687
PRIMARY VOLT. 104.0 ± 1.0%
102.1 ± 1.0% (LONG Ø)
101.2 ± 1.2%

Figure 7. Economic comparison of several methods of improving voltage on a three-mile single-phase branch at the end of a three-phase four-kv distribution feeder

5. Reduce voltage drop in the existing circuit by means of series capacitors, which can be selected to give a voltage rise to compensate for the voltage drop in the conductors.

Several methods may be used in combination, such as

6. Install as much fixed shunt capacity as circuit conditions permit, advancing the feeding point or rebuilding the substation end of the circuit to secure the remainder of the required voltage correction.

7. Install as much fixed shunt capacity as circuit conditions permit, adding automatic voltage boosters to correct for excessive drop beyond the shunt capacitors.

Any of these methods can be applied to correct the voltage regulation of a distribution circuit which exceeds the permissible limits of steady-state voltage. Economics now enters as an important factor in selecting the one method most applicable to the case at hand. The previous paper presented a number of comparisons of the first three methods applied to typical circuits. These examples, corrected for increased construction costs and with the new methods added, are presented herein as figures 6, 7, and 8.

Shunt capacitors automatically connected during periods of low voltage and disconnected during periods of high voltage, used in combination with fixed shunt capacitors to secure more voltage correction than can be secured with fixed capacitors alone, did not in any case give as low a total cost of correction as could be attained with the combination of automatic boosters and fixed shunt capacitors. The automatic shunt capacitor does not seem to offer any real advantage and may well be dropped from further consideration as a device for general use to correct voltage on distribution feeders.

The series capacitor also is higher in total cost than several other methods and need not be considered further as a means for the correction of voltage drop in distribution feeders. An exception must be made, however, for fluctuating loads which require the reduction of circuit impedance either by increasing copper size or by the installation of series capacitors or proper current rating and capacitance, but this is a problem in itself, entirely separate from the scope of the present paper.

The lowest total cost in every case is secured by the combination of several methods. The installation of fixed shunt capacitors well out on the circuit near the point where the peak-load drop from the feeding point approaches 5.0 per cent almost pays for itself in the value of the system capacity released by the reduction in amount of reactive current to be supplied, and provides considerable voltage correction at low net cost. Fixed shunt capacitors may be added until the light-load voltage reaches the maximum or the circuit power factor reaches unity, whichever comes first. Any additional voltage correction required can be secured by means of automatic voltage boosters beyond the shunt capacitors.* The installation of shunt capacitors and one set of automatic boosters compensates for 5.66 per cent voltage drop and permits loading the circuit to 288 per cent of the limit established by voltage drop without any of these supplementary devices. Additional automatic boosters might be installed, but sooner or later the point is

* Fixed shunt capacitors should not be installed beyond voltage boosters as there are no compensators to overcome undesirably high voltage during light-load periods.

reached where it is more economical to rebuild the circuit for greater capacity and better regulation. This point depends largely upon the length of circuit and the conductor sizes, but it is doubtful whether two sets of boosters in series beyond a maximum installation of fixed shunt capacitors can be justified on four-kv circuits up to five or six miles long.

Long single-phase branches connected near the feeding point of a three-phase circuit also should have fixed shunt capacitors. Any additional voltage correction required should be secured by extending the second and third phases; considerable voltage improvement is accomplished by a comparatively short extension of the additional phases and the cost generally is less than that of automatic voltage boosters on the single-phase circuit.

Adaptability to Growing Loads

The final test of any proposal affording comparable service is whether its use results in lowered total costs over a period of years. The earlier paper showed the annual cost through a 30-year period of growth of two typical circuits using automatic voltage boosters for voltage correction as compared with the conventional methods of rebuilding. The same two circuits have been analyzed using fixed shunt capacitors to the limits of unity power factor and 3.0 per cent voltage rise, followed by other methods of correction.

In the first case, the circuit originally consisted of two number 3 copper wires single-phase extending three miles from a feeding point having peak load voltage of 104.0 ± 1.0 per cent. The load originally was 20 kva distributed uniformly along this three-mile feeder and the voltage drop was entirely satisfactory, but load growth at the rate of ten per cent per year soon increased the drop to the limit. At this point a shunt capacitor is installed two miles from the feeding point to correct the voltage. Continued growth exhausts this means of correction and the circuit is then gradually converted to three phase. The steps are shown in figure 9 along with correction by boosters and by circuit rebuilding alone. The relative costs are plotted in figure 10. It is obvious that the conversion from single-phase to three-phase is delayed, with a savings of four per cent in accumulated annual cost.

In the second case the circuit originally consisted of four number 3 copper wires three-phase extending three miles from a feeding point having three-phase voltage of 104.0 ± 1.0 per cent. The load originally was 100.5 kva uniformly distributed along the feeder and well balanced, and the voltage drop was satisfactory, but load growth at the rate of ten per cent per year soon increased the drop to the limit. At this point fixed shunt capacitors are installed two miles from the feeding point to correct the voltage. Continued growth necessitates further correction and a set of automatic voltage boosters is added, followed by circuit rebuilding and additional capacitors. The steps are shown in figure 11, along with correction by boosters and by circuit rebuilding alone, and the relative costs are plotted in figure 12. Again it is clear that the capacitors and boosters together have delayed the more expensive rebuilding and have accomplished a substantial savings in annual costs.

Conclusions

These growing-load comparisons confirm the conclusion indicated by the sev-

Figure 9. Periodic alterations on three-mile 2,300-volt single-phase branch at the feeding point of a three-phase four-kv distribution feeder to maintain primary voltage within limits of 105 and 100 per cent for load growth of ten per cent per year

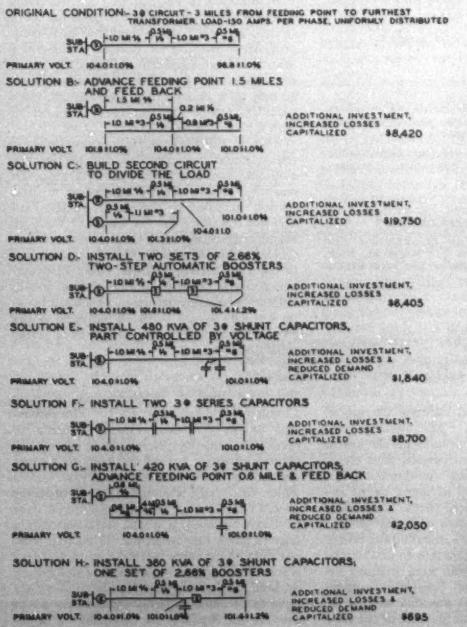
ORIGINAL CONDITION- 3Φ CIRCUIT - 3 MILES FROM FEEDING POINT TO FURTHEST TRANSFORMER. LOAD-150 AMPS. PER PHASE, UNIFORMLY DISTRIBUTED
PRIMARY VOLT. 104.0±1.0% 98.8±1.0%
SOLUTION B:- ADVANCE FEEDING POINT 1.5 MILES AND FEED BACK
ADDITIONAL INVESTMENT, INCREASED LOSSES CAPITALIZED $8,420
PRIMARY VOLT. 101.8±1.0% 104.0±1.0% 101.0±1.0%
SOLUTION C:- BUILD SECOND CIRCUIT TO DIVIDE THE LOAD
ADDITIONAL INVESTMENT, INCREASED LOSSES CAPITALIZED $19,750
PRIMARY VOLT. 104.0±1.0% 101.3±1.0% 104.0±1.0
SOLUTION D:- INSTALL TWO SETS OF 2.66% TWO-STEP AUTOMATIC BOOSTERS
ADDITIONAL INVESTMENT, INCREASED LOSSES CAPITALIZED $6,405
PRIMARY VOLT. 104.0±1.0% 104.8±1.0% 101.4±1.2%
SOLUTION E:- INSTALL 480 KVA OF 3Φ SHUNT CAPACITORS, PART CONTROLLED BY VOLTAGE
ADDITIONAL INVESTMENT, INCREASED LOSSES & REDUCED DEMAND CAPITALIZED $1,840
PRIMARY VOLT. 104.0±1.0% 101.0±1.0%
SOLUTION F:- INSTALL TWO 3Φ SERIES CAPACITORS
ADDITIONAL INVESTMENT, INCREASED LOSSES CAPITALIZED $8,700
PRIMARY VOLT. 104.0±1.0% 101.0±1.0%
SOLUTION G:- INSTALL 420 KVA OF 3Φ SHUNT CAPACITORS, ADVANCE FEEDING POINT 0.8 MILE & FEED BACK
ADDITIONAL INVESTMENT, INCREASED LOSSES & REDUCED DEMAND CAPITALIZED $2,050
PRIMARY VOLT. 104.0±1.0% 101.0±1.0%
SOLUTION H:- INSTALL 360 KVA OF 3Φ SHUNT CAPACITORS, ONE SET OF 2.66% BOOSTERS
ADDITIONAL INVESTMENT, INCREASED LOSSES & REDUCED DEMAND CAPITALIZED $695
PRIMARY VOLT. 104.0±1.0% 101.0±1.0% 101.4±1.2%

Figure 8. Economic comparison of several methods of improving voltage on a three-mile three-phase four-kv distribution feeder

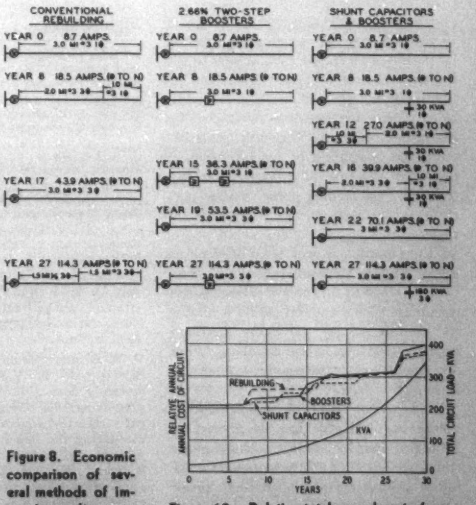
CONVENTIONAL REBUILDING
2.66% TWO-STEP BOOSTERS
SHUNT CAPACITORS & BOOSTERS
YEAR 0 87 AMPS.
YEAR 8 185 AMPS. (@ TO N)
YEAR 12 270 AMPS. (@ TO N)
YEAR 15 363 AMPS. (@ TO N)
YEAR 16 389 AMPS. (@ TO N)
YEAR 17 439 AMPS. (@ TO N)
YEAR 19 535 AMPS. (@ TO N)
YEAR 22 701 AMPS. (@ TO N)
YEAR 27 1143 AMPS. (@ TO N)
REBUILDING
BOOSTERS
SHUNT CAPACITORS
KVA
RELATIVE ANNUAL COST OF CIRCUIT
TOTAL CIRCUIT LOAD - KVA
YEARS

Figure 10. Relative total annual cost of serving a load growing ten per cent per year on a three-mile 2,300-volt feeder initially single-phase with number 3 conductors

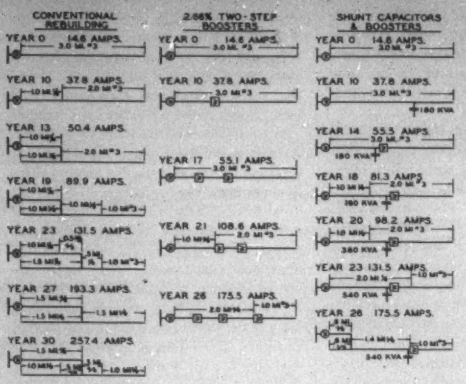

Figure 11. Periodic alterations on three-mile four-kv three-phase circuit to maintain primary voltage within limits of 105 and 100 per cent for load growth of ten per cent per year

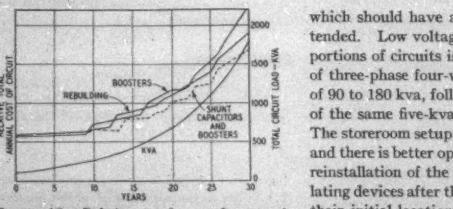

Figure 12. Relative total annual cost of serving a load growing ten per cent per year on a three-mile feeder initially four-kv three-phase with four number 3 conductors

eral static comparisons that correction of voltage on four-kv distribution circuits by means of fixed shunt capacitors to the limit established by power factor and by light-load voltage, followed, when additional correction becomes necessary, by one set of automatic voltage boosters beyond the capacitors or by extension of phases in the case of a single-phase tap from near the feeding point, makes possible substantial savings in the cost of maintaining proper voltage at all points on the circuit. It was very obvious at many points in the comparisons that careful adherence to this policy is essential to maximum economies and that it is unwise to attempt to use too many auxiliary regulating devices before installing 1/0 or 4/0 conductors in the heavier-loaded portions of the circuit.

Only three types of supplementary voltage-regulating devices are needed for suburban four-kv feeders. Single-phase shunt capacitors of 30 kva are used for the initial voltage correction on single-phase extensions, followed by single-phase five-kva automatic voltage boosters with two 1.33-per-cent steps except on a single-phase tap from near the feeding point which should have additional phases extended. Low voltage on the three-phase portions of circuits is corrected by means of three-phase four-wire shunt capacitors of 90 to 180 kva, followed by sets of three of the same five-kva automatic boosters. The storeroom setup is thereby simplified, and there is better opportunity for prompt reinstallation of the supplementary regulating devices after they are removed from their initial locations. This system provides worthwhile economies in the cost of distribution, and delays major changes until more load has developed to give a better indication of future needs.

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4. Shunt Capacitors on Distribution Circuits, George P. Gamble and Frank M. Starr. *General Electric Review*, October 1936, pages 466–74.

5. Capacitors—Design, Application, Performance, M. C. Miller. *Electric Light and Power*, October 1938, pages 46–50.

Discussion

P. E. Benner (General Electric Company, Schenectady, N. Y.): Mr. Olmsted has certainly done a very commendable job in presenting this straightforward and clear-cut method of analyzing the operation and evaluating the benefits of using shunt capacitors in connection with automatic boosters. He has shown that by proper application of capacitors installed for power factor correction it is possible to double the primary drop in the load area without increasing the limits of consumer voltage variation. This makes possible the use of smaller conductors or an increase of the load area served by any particular feeder

The author arrives at a value of three per cent as the maximum permissible correction by means of shunt capacitors. In this connection it is important to note that this three per cent correction is between the first transformer and the capacitor installation, and does not refer to the voltage rise from the capacitor clear back to the substation. It should be further noted that this three per cent correction or voltage rise does not take into account the possibility of using a branch feeder regulator with a buck as well as a boost range installed between the capacitor installation and the first transformer. The installation of such a branch feeder regulator with line-drop compensator would, of course, double the permissible voltage rise due to the capacitor, thereby raising the limit of three per cent to six per cent.

By limiting himself to the use of a two-step booster the author cannot take full advantage of shunt capacitor applications in that in many cases it would not be possible to locate the capacitor as far out on the circuit as might otherwise be desirable. It is believed that the small cost differential between the two-step booster and the four-step regulator with line-drop compensation would easily be offset by the postponement of the time of changing a circuit to three-phase or installing larger copper. The four-step regulator of conventional design can be connected for two steps raise and two steps lower, and therefore would permit the use of a shunt capacitor located further out on the line. Such an installation would make it possible to double the allowable primary drop as shown by the author in figure 3.

In addition to the author's five methods for correcting the voltage regulation of a circuit, it would seem desirable in a comprehensive analysis to consider the use of a branch feeder regulator of either the four-step or the induction type which have a buck as well as a boost range and are therefore particularly adaptable for use in conjunction with a shunt capacitor.

Also, in cases where voltage regulation is the primary consideration one should not overlook the possibility of obtaining the desired voltage rise by means of a fixed booster installed in the circuit in the load area as discussed in the paper, "Voltage-Regulating-Equipment Characteristics as a Guide to Application" which was published in the 1938 AIEE Transactions (September section). It is usually possible to obtain voltage correction by means of a fixed booster for only about 10 to 15 per cent of the cost of obtaining it by means of a shunt capacitor.

Raymond Bailey (Philadelphia Electric Company, Philadelphia, Pa.): The discussion in Mr. Olmsted's paper relating to credit for capacity released in a system by the use of static capacitors leads to a more general question as to conditions under which full credit for such system capacity should be allowed. From the point of view of sound business, it would seem reasonable only to allow full credit on the basis of cost per unit of capacity installed in those cases where this released capacity permits taking on load where otherwise investment would have to be made in the immediate future to provide the capacity for this load. For ex-

ample, it is questionable how much credit should be allowed in a case where the use of static capacitors on distribution circuits releases capacity in the step-down transformers in a substation which are at present rather lightly loaded, as it may be an appreciable number of years until this released capacity is actually needed to carry load. A more or less parallel case exists in determining credit for released generating capacity and here one must consider what actual effect this released capacity would have on the future investment to provide generating capacity.

It will be found in many cases that it is sound business to allow as a credit only a certain proportion of the cost per unit of capacity in place, depending upon the time that will elapse before this capacity is actually needed.

This matter of value of system capacity is one that frequently arises in economic problems that have to do with public utility systems and it is believed that it deserves a very searching review by public utility engineers in order to avoid balancing on one hand an actual expenditure of money against calculated credit which may not represent a real saving.

C. E. Arvidson (The Commonwealth and Southern Corporation, Jackson, Mich.): Mr. Olmsted's paper shows economic comparisons of various methods of correcting excessive voltage drops in distribution circuits and justifies the use of capacitors largely by capitalizing the released system capacity resulting from the capacitor installations. Does this released system capacity have any value during an interim when the transmission lines and substations involved are not loaded to capacity? In cases where the transmission lines or substations are loaded to capacity, does not the installation of capacitors serve to postpone the installation of additional system capacity rather than replace such additions? If capacitors can be considered as a means of permanently releasing system capacity, should not investigations be made to justify their installation on all distribution circuits regardless of existing voltage conditions?

It is the writer's opinion that the economic value of capacitors as a means of voltage correction depends upon existing conditions and that other methods of voltage correction may often be more economical than capacitors.

L. H. Hill (Allis-Chalmers Manufacturing Company, Milwaukee, Wis.): Mr. Olmsted is to be congratulated on his very thorough discussion of various means of regulating distribution feeders. It is evident from the paper that the elimination of wattless current on distribution feeders is highly desirable. In this regard the author apparently has overlooked the great saving in exciting kilovolt-amperes obtained by the use of step-type feeder voltage regulators instead of the induction type as referred to in the paper.

For example, induction-type regulators used to regulate the 1,500-kva feeder referred to in the paper require approximately 37.5 kva for excitation. On the other hand, step-type regulators for this same service require only about 7.5 kva for excitation—a net saving of 30 kva. This means that 30 kva, or almost ten per cent of the capacitors, could be eliminated by the substitution of step-type regulators for the induction type now used. Since capacitors are priced at about $8.00 per kilovolt-ampere, this would result in a direct saving of $240.00.

If capacitors were not used, an even greater advantage can be shown for the step-type regulator. The reduction of 30 kva in wattless current on this particular feeder would result in a decrease in demand of 12.4 kva. When capitalized at $50.00 per kilovolt-ampere according to the paper, this reduction in demand would amount to a saving of $620.00.

From these two illustrations it is evident that much can be done in the way of selecting equipment to release system capacity without resorting to capacitors. Even if capacitors are found desirable, however, the step-type regulator greatly reduces the number required.

J. W. Butler (General Electric Company, Schenectady, N. Y.): In view of my interest in the application of series capacitors I would like to comment briefly on their use in the circuit regulation picture, in addition to that considered by Mr. Olmsted.

Admittedly this paper and its presentation was not required to dwell on this point since the objective was to determine the most economical way to take care of the type of regulation that could be handled in several different manners as listed in figure 8. Series capacitors, however, are able to furnish a type of regulation in addition to that type dealt with in the paper that can be furnished by no other piece of regulating equipment. This discussion is given for the benefit of those individuals not intimately acquainted with the subject in case their opinion of the series capacitor was formed in substance by the account given by Mr. Olmsted.

A series capacitor gives a boost in the line voltage at the point of application as determined by its ohmic value and the power factor of the current. This boost takes place at the capacitor—hence the circuit on the power-source side has the same regulation as it had before installation. The voltage on the load side, however, is changed and for any given power factor and circuit, the voltage at a preferred location can be made to have practically zero regulation. The rest of the circuit, however, will have regulation, either plus or minus, depending upon its location with respect to the capacitors. Obviously then for a circuit having a distributed load, two or more series capacitors probably would have to be used to give satisfactory regulation to the complete circuit. It is this point that makes the series capacitor appear in an unfavorable light when considering Mr. Olmsted's problem.

Consider however a feeder having substantially no load taken from it until it gets to a bus, where there might be a saw mill, an electric dredge, a large motor that is intermittently started, or some other type of pulsating load that causes severe voltage fluctuations at the bus affecting all other connected loads, such as city lighting. Since the series capacitor produces its compensation *automatically* and *instantaneously*, it enjoys a unique position in the regulating field in being able to cure this type of voltage fluctuation.

Paul H. Jeynes (Public Service Electric and Gas Company, Newark, N. J.): This paper deals with a subject that has been carefully investigated by Public Service engineers, and it can be said that in general our experience and conclusions parallel closely those reported by Mr. Olmsted. Differences in detail may perhaps be accounted for by peculiarities of load conditions on the two systems.

For example, the statutory voltage tolerance in New Jersey is most rigorous, being plus or minus three per cent—not five per cent. In addition, we are acutely conscious of the error in supplying unnecessarily high voltage to the customer, both on ethical grounds and for the sake of good public relations. Although studies have demonstrated that the effect of increased voltage (within this three per cent) on customers' bills is practically negligible, this factor is vastly overrated in the minds of many—engineers as well as laymen. The use of the shorter-lived Mazda lamps is liable to create a suspicion that unduly high voltage may be responsible for the increased lamp renewals. In either event, it is important to be able to demonstrate that infinite pains are taken to avoid the condition.

Other characteristics of the Public Service system are the high power factors ordinarily encountered at time of peak loads, and the moderately high load density in the territory served. While we do have areas that we consider to be "rural," by some standards even these would be classified as zones of fairly good density.

One apparent difference which results from the above considerations is the matter of compensating primary circuits. Maximum permissible voltage is not maintained at the point of feed—that is, the first transformer on the circuit—unless that is necessary in order to keep the last customer from dropping below the permissible minimum. In other words, circuits are compensated to maintain nominal voltage at some point well out on the primary, which tends to reduce the voltage improvement to be expected from shunt capacitors attached at the end of the circuit.

Another effect of the small voltage tolerance is that the range of single-step boosters must be limited to five per cent, as a rule, while no applications for multistep boosters have yet been found.

Automatic Boosters

A number of automatic-booster installations are giving satisfactory service and have proved to be cheaper than any alternative. On a few occasions boosters were installed only to have it appear that this was the wrong answer. The difficulty lay in the type of load, which resulted in an almost unpredictable daily voltage cycle, and too frequent operation of the controls. In one case we were able to avoid trouble by using a time switch to cut out the automatic operation during daylight hours when the circuit supplied only power load, which caused the difficulty.

Like Mr. Olmsted we had discovered that the combination of booster and shunt capacitor is ideal for certain situations, but refrained from reporting on the subject only because we have made no actual installations. Our nearest approach is a recently completed combination of pole-type induction regulator with capacitors at the end of

single-phase branches beyond the regulator. This has solved a difficult problem and is giving almost ideal service.

Shunt Capacitors

As Mr. Olmsted points out, light-load conditions usually limit the size of capacitor installations for voltage improvement. About 1,000 kva of 15-kva units are installed on Public Service lines, and we are enthusiastic about them. They give maximum relief at the point of attachment, where it is most needed, and the effect tapers off back to the center of regulation; as a result, they minimize the undesirable overvoltage supplied to customers nearer the substation, which is just the reverse of a boost applied part way out on the circuit.

We have not as yet made any installations switch-controlled by the voltage, though we have numerous units on pole-type constant-current transformers that cut in with the transformer when the street lights are turned on. The proposal for voltage control of capacitors connected does have appeal, particularly because the voltmeter would be located at the point of maximum voltage variation. This of course is not the case for boosters; the resultant debate over voltage versus current control of boosters is familiar to all. In any event, it appears to be purely a matter of relative costs; we are not yet ready to rule out automatically controlled capacitors as a future possibility.

"Released Capacity" Savings

On this subject of savings from "released capacity" in the supply system we are forced to differ with Mr. Olmsted—not in criticism of his figures, but of his general approach to the problem of evaluating savings. An important addition to his bibliography is proposed, being a brief comment by Alex Dow which appeared in the *Electrical World* for January 10, 1925.

Sometimes fantastic savings result from power-factor improvement. But unless *without* capacitors we would have to spend money that would not be spent *with* capacitors, these "released capacity" savings are worth zero dollars per kilovolt-ampere. Installations of the small amounts of leading reactive capacity required for voltage improvement very rarely affect the program for feeder, substation, or transmission capacity installations, in our experience. Even when capacitors can be justified by resultant postponement of capacity installations, the postponement is only temporary; a point is reached where the power factor approaches unity, the capacity must be installed in any event, and the capacitors are for a time of no further use.

The most fruitful source of savings in our experience lies in postponement of incremental substation transformers, and this possibility of savings is investigated whenever growing loads indicate that additions are imminent. Frequently postponement for a short period is found justified—usually two to four years—provided immediate use can be found for the released capacitors when, at the end of that time, the transformers must be installed in any event. Usually, also, no coincidental installations of transmission or other capacity are on the books during that period, so that the hypothetical "released capacity" savings beyond the transformers are nil.

The fantastic savings mentioned above were realized when, after a small installation of capacitors had made the postponement effective for one year, the load unexpectedly dropped off. Had the transformers been installed we would now be saddled with carrying charges of perhaps $5,000 annually, but the capacitors, having effected that saving, have been transferred to other locations where they are earning their keep and compounding the savings.

To sum up the foregoing argument, it seems wise to ignore possible prorata kilovolt-ampere savings from "released capacity" unless their specific source can be pointed out. If capacitor installations are justified despite this omission, any real credit from such a source is "velvet."

We have been unable to formulate any general rule to indicate the economic preference for polyphase, increased wire size, boosters, or capacitors; each case requires individual study.

Series Capacitors

Public Service experience with series capacitors is adequately covered by Mr. Olmsted's bibliography. At the present time another similar installation is being considered, and like its predecessors it is proving to be a delicate engineering problem. Series capacitors resemble the well-known little girl with a little curl right in the middle of her forehead—when they are good they are very, very good.

L. M. Olmsted: Mr. Butler calls attention to the fact that the series capacitor, in addition to its ability to correct steady-state voltage conditions, has the unique advantage of being instantaneous in effect and thereby correcting fluctuating voltage conditions too rapid to be corrected by any of the other devices. In a paper specifically limited to the correction of steady-state conditions it seemed unwise to discuss fluctuating voltage. Consequently the series capacitor, found uneconomical for steady-state conditions, was dismissed with only a suggestion as to its other advantages. I am glad that Mr. Butler has discussed the most advantageous field for the series capacitor and corrected any impression that the series capacitor is never desirable.

Messrs. Arvidson, Bailey, and Jeynes all have commented on the credit for system capacity released by the power-factor improvement coincident with the correction of low voltage by means of shunt capacitors. Admittedly the value of this system capacity depends upon the ability to postpone the installation of additional system generating, transmission, substation, or distribution facilities. Every case is different, and the true value ranges from almost zero to such "fantastic savings" as mentioned by Mr. Jeynes. The same question arises in the evaluation of losses, in attempting to assign a fair increment above the fuel cost to cover the use of system investment. The figure of $50 per kilovolt-ampere of system capacity released by the capacitors is consistent with the capitalized valuation of losses (omitting generating capacity which is already operating above rated power factor). Raising or lowering this credit for released capacity to suit some particular conditions might affect the choice of shunt capacitors for economical correction of voltage, might even justify the installation of shunt capacitors where voltage is satisfactory solely to postpone system expansion, but it cannot affect the economic advantage which all of the supplementary regulating devices hold in common over conventional line rebuilding, the advantage of high reclaim value for use elsewhere.

Mr. Jeynes' comments indicate very close similarity indeed between Public Service findings and our own. Even though the statutory limits in Pennsylvania are more liberal, the many thousands of voltage checks made by our troublemen on their service calls indicate that 90 per cent of our consumers receive voltage within ±2.5 per cent of nominal. We consider it advisable to restrict the amount of boost at any one location to less than 5 per cent but favor two small steps instead of one larger step. The apparent difference in the method of compensating primary circuits for line drop probably is negligible, as we have only recently changed from the method described by Mr. Jeynes to the one described in this paper in order to secure more accurate supervision over the voltage actually supplied to all consumers at their service switches; it is designed to check the upper and lower limits of voltage instead of testing the average consumer.

All of our automatic boosters are equipped with time delay of approximately 50 seconds. This delay has been found desirable to permit close voltage settings without too frequent operations of the tap changers. No conditions have been encountered where this arrangement has permitted excessive operations.

Mr. Benner points out that line-drop compensation can be added to pole-mounted voltage regulators, after which shunt capacitors might be installed at the ends of the circuit. With this combination, the voltage boost of the shunt capacitors benefits the entire circuit during heavy-load periods and overvoltage during light load is prevented by bucking action in the pole-mounted regulators. This combination was not considered in the paper because it was thought desirable to keep pole-mounted equipment as simple as possible and also because of the difference in cost between pole-mounted regulators and two-step boosters, but its feasibility is proved by Mr. Jeynes' discussion and it may have greater economic advantages than I had anticipated.

The fixed booster undoubtedly gives inexpensive voltage correction and should be considered, especially if no value is placed upon the released capacity coincident with voltage correction by means of shunt capacitors. In one case fixed boosters have been considered to correct for drop in a long feeder, but the cost was high because of the current to be carried and shunt capacitors near the ends of the branches, credited with reduction in losses and released capacity, gave much lower net cost.

Mr. Hill points out a very interesting advantage which step-type regulators have over the induction type. The lower exciting current, in combination with lower price, certainly merits some thought.

All of the discussers have been most helpful in adding to the information available and in indicating various other problems to consider in the effort to secure necessary voltage correction in the most economical way.

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Industrial Notes

Commonwealth Edison Orders Towers.—The Blaw-Knox Co., Pittsburgh, reports an order received from the Commonwealth Edison Co., for 500 transmission towers, involving approximately 5800 tons of steel. These towers include the latest improvements in design and fabrication, and will be used to extend the power company's service between Powerton and Crawford, Ill., a distance of about 130 miles.

Electrical Equipment for Steel Mill.—Electric drive equipment designed to operate a four-stand, tandem, cold reduction strip mill, at rolling speeds higher than any now in use for this type of mill, has been ordered from the Westinghouse Electric & Mfg. Co. for a relocated mill of the Weirton Steel Co. at Weirton, W. Va. The order includes four mill motors with a combined power output approaching 5,000 horsepower, a 300-hp reel motor, a 5,000-kw main motor-generator set and a 650-kw auxiliary motor-generator set. . . . . The steel company has also ordered a 10,000-kw, 3600-rpm topping steam turbine and generator from the Allis-Chalmers Mfg. Co. This unit will be of the impulse reaction type, designed for an initial steam pressure of 800 pounds.

New NEMA Report on Building Wire.—The Rubber Covered Building Wire Section of NEMA has published a report entitled "NEMA Report on Investigation of Small Diameter Building Wire." The type of small-diameter building wire covered in this report has a "heat resistant" grade of rubber insulation capable of sustained operation at a temperature up to 75°C. In comparison, the standard type R Code Grade Wire has a maximum temperature rating of only 50°C. The insulation thickness of this small wire is $^1/_{32}$ inch for sizes 14, 12 and 10; and $^3/_{64}$ inch for size 8 Awg (a reduction of $^1/_{64}$ inch from the present code grade thickness). Copies of the report, which includes tables for current-carrying capacity, may be obtained from NEMA headquarters, 155 East 44th St., New York City, for 25 cents.

Trade Literature

Circuit Breakers.—Cat. 5, 12 pp. Describes heavy-duty air circuit breakers; capacities up to 10,000 amperes; 600 volts a-c; 750 volts d-c; live front; dead front; steel enclosed. Roller-Smith Co., Bethlehem, Pa.

Connectors.—Catalog. Describes a wide variety of pressure connectors applicable to many requirements of wire and cable joining. National Electric Products Corp., Fulton Bldg., Pittsburgh, Penna.

Transformers.—Bulletin GEA-3085A, 12 pp. Describes "Spirakore" distribution transformers, single phase, oil immersed, embodying the new wound core design. General Electric Co., Schenectady, N. Y.

Connectors.—Bulletin 205, 6 pp. Describes nut-type wire connectors and service entrance and parallel clamp connectors. W. N. Matthews Corp., St. Louis, Mo.

Linemen's Safety Equipment.—Catalog. Describes safety equipment for the use of linemen, including body belts, safety straps, tools, line blankets, rubber gloves and garments. Davis Emergency Equipment Co., 55 Van Dam St., New York City.

Connectors.—Catalog 41, 64 pp. Describes numerous types of copper and aluminum connectors for cables, tubes, wires and bars. Technical data on insulated cables and current carrying capacity of bars is included; prices are listed. Burndy Engineering Co., Inc., 459 E. 153rd St., New York City.

Voltage Regulators.—Bulletin 202M, 4 pp. Describes vibratory voltage regulators. They are suitable for voltage regulation of a-c and d-c generators and when used in connection with synchronous motors and condensers, provide an efficient means of power factor correction, according to the manufacturer. The Simplex Corp., Burlington, Iowa.

Bimetals.—Publication "Blue Book on Bimetals." Covers recommendations, specifications on dimensions, hardness, tolerances, heat treatment, allowable loads and derivation of formulae on a series of bimetals, to assist in the selection of the correct type for any requirement. Data on electrical contacts is included. H. A. Wilson Co., 105 Chestnut St., Newark, N. J.

Metal-Enclosed Switchgear.—Bulletin GEA 2596A, 16 pp. Describes metal enclosed switchgear with draw-out air circuit breakers, for low-voltage feeders; ratings up to 10,000 amperes at 600 volts a-c; 250 volts d-c, and with interrupting ratings to 80,000 amperes, manually or electrically operated. General Electric Co., Schenectady, N. Y.

Variable Transformers.—Bulletin 148, 8 pp. Describes the "Powerstat" line of variable transformers for obtaining manual a-c voltage control. Included is technical data on single- and three-phase units for 115-, 230- and 440-volt circuits in capacities up to 25 kva. Superior Electric Co., Bristol, Conn.

Disconnecting Devices.—Bulletin 135, 20 pp. Describes a complete line of high voltage disconnecting devices ("Isolators") applicable between bus and cable, in switching cabinets and cubicles, outdoor switch houses and for many other purposes. Features of these devices include: space saving due to compactness of design, labor saving because of easy installation; insulators and connectors may be eliminated, and operating safety is assured. A few of numerous installations are illustrated. Electrical Engineers Equipment Co., Melrose Park, Ill.

Air Circuit Breakers.—Catalog 538, "Itelite Circuit Breakers." A general catalog of type ET breakers for load centers, power panels, panelboards, switchboards and individual mounting. Gives prices, types, dimensions, operating characteristics and continuous ratings. I-T-E Circuit Breaker Co., 19th & Hamilton Sts., Philadelphia, Pa.

Lubricated Sliding-Contact Rheostats.—Bulletin 1620, 4 pp. Describes improved Jagabi sliding-contact rheostats which are now provided with a graphite lubricator, improving the contact, eliminating scratching and abrasion, and permitting a marked smoothness of fine adjustment; price list is included. James G. Biddle Co., 1211 Arch St., Philadelphia, Pa.

Steel-Enclosed Switchgear. Bulletin B6012, 12 pp. Describes a complete line of vertical-lift, metal clad switchgear for control of generators, motors, incoming lines, feeders, bus tie circuits, etc. Bulletin B-6011, 12 pp., describes cubicle type switchgear with many new installation views, dimension sheets and wiring diagrams, as well as application and construction data. Allis-Chalmers Mfg. Co., Milwaukee, Wis.

Water Resistant Cable Insulation.—Revised Bulletin, 20 pp. Describes "Anhydrex" rubber insulation for electrical conductors. The resistance to water absorption of this insulation, according to the manufacturer, makes it suitable for use on every type of non-leaded communication and power cable. Includes comprehensive tests on insulation water absorption and related data. Simplex Wire & Cable Co., 79 Sidney St., Cambridge, Mass.

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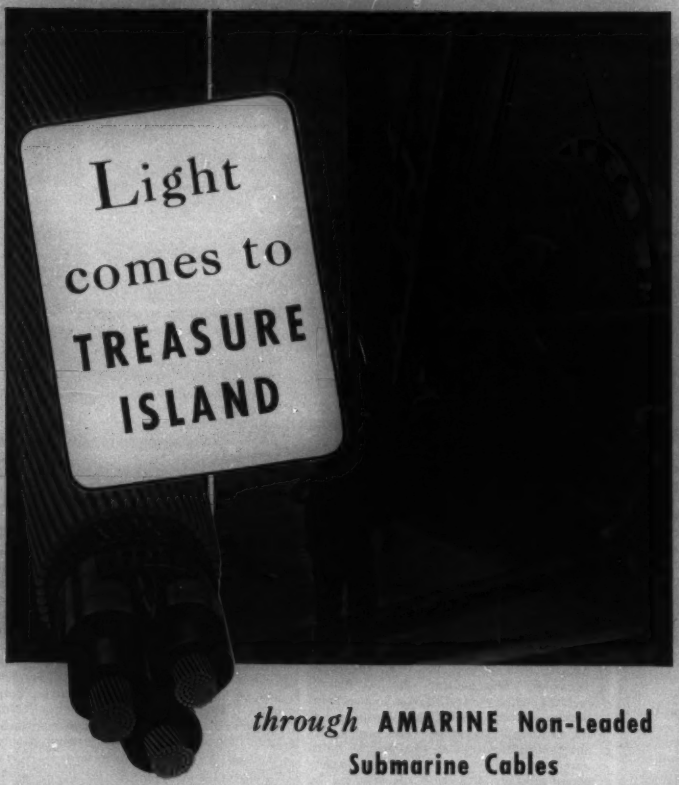

through AMARINE Non-Leaded Submarine Cables

NEW heights in the art of illumination have been attained at the Golden Gate International Exposition. First to be perceived by the visitor, and perhaps last to be forgotten, are the novel lighting effects. These are dependent upon electrical energy—energy carried to the Island by *Amarine* non-leaded submarine cables, laid beneath the waters of San Francisco bay.

Each cable is composed of three stranded copper conductors, insulated with Amarine-40 rubber compound for service at 11,000 volts. Armored with heavily galvanized steel wires, it has an outer diameter of more than 4 inches and weighs 18 pounds per foot. Each conductor of the shore end is shielded with tinned copper tape. A thin layer of semi-conducting material, applied between rubber insulation and copper tape and in intimate contact with both, assures positive and permanent shielding.

The new cables, installed in 1938, lie not far from two other Amarine non-leaded submarine cables that were installed in the same bay 16 years ago, and which are still in good condition and giving satisfactory service.

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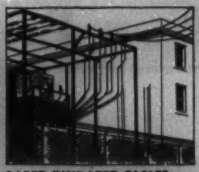
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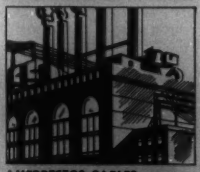
AMARINE NETWORK CABLES

VARNISHED CAMBRIC CABLES

RELIANCE WEATHERPROOF WIRES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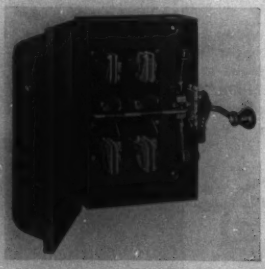
UNITED STATES STEEL

New Products

Multi-Range Clip-On Ammeter.—A new multi-range, clip-on ammeter has been announced by Ferranti Electric, Inc., 30 Rockefeller Plaza, New York City. This instrument reads from 0 to 1000 amperes, having five full scales of 0–10/–25/100/250/–1000 amperes. There is only one single, simple set of scale divisions and all full scales are multiples of 10 or 25. The meter is well balanced, easy to operate and has clamping jaws which are well insulated. A $2^1/_4$-inch square opening makes it adaptable for use on square busbars as well as round cables.

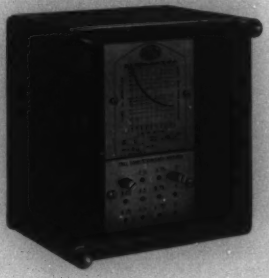
Ferranti clip-on ammeters have been widely used by industrials and central stations for checking current loads since their introduction nearly ten years ago.

Double Throw Switches.—A new line of unfused type A, double throw switches, has been developed by The Square D Co., Detroit, Mich. These switches are made in



full type "A" construction, having quick make and break, cover interlock, and padlocking divisions for three padlocks in the "Off" and "On" positions. Switches are of unit base construction, have the new V-type blade, multi-spring jaws and the compression spring construction of the Square D quick make and break mechanisms. The switches now in production include 60-, 100-, and 200-ampere sizes, both 2- and 3-pole. All sizes are listed with the Underwriters' Laboratories for either 230 volts or 575 volts, a-c, as well as 250 volts, d-c.

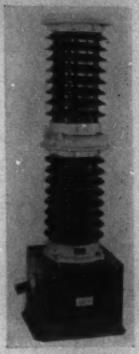
Thermo-Magnetic Relay.—This new, type DT-1 thermo-magnetic relay, introduced by the Roller-Smith Co., Bethlehem, Pa., is designed for the protection of a-c apparatus, such as motors, generators and transformers, which is subject to either momentary or continuous overloads. The time delay element is of a new type, consisting of a heater and bi-metallic strip combination, fully compensated for ambient temperature. The relay can thus be located at any dis-



tance from the apparatus being protected, and will always operate on current values directly without influence from any other variables. The heating rate of the bi-metallic strip is controlled so as to match approximately the heating rate of windings of the protected apparatus. The instantaneous element operates at 10 times the minimum operating current which is determined by the tap setting. Relays can be supplied with various special features such as different time delay characteristics and different instantaneous element operating points to meet special applications.

Textolite Cutouts.—A further extension of the use of "Textolite" instead of porcelain in certain items of the G-E wiring device line has been announced by the General Electric appliance and merchandise department, Bridgeport, Conn., with the introduction of four new enclosed fuse cutouts and a new lampholder for sign work. The Textolite cutouts supersede four porcelain cutouts in the present line, with catalog numbers remaining the same. All black in color, the new cutouts are lighter in weight and have a higher resistance to breakage, provide better alignment of contacts, and clips are held firmly in place. Prices have not been increased. The new one-piece Textolite lampholder for sign work likewise replaces a porcelain lampholder with the same number. It is designed for use in metal signs with binding screw terminals and is particularly fitted for such applications because it is light in weight, easy to handle, and does not break. The lampholder is keyless and is rated at 660 watts, 250 volts.

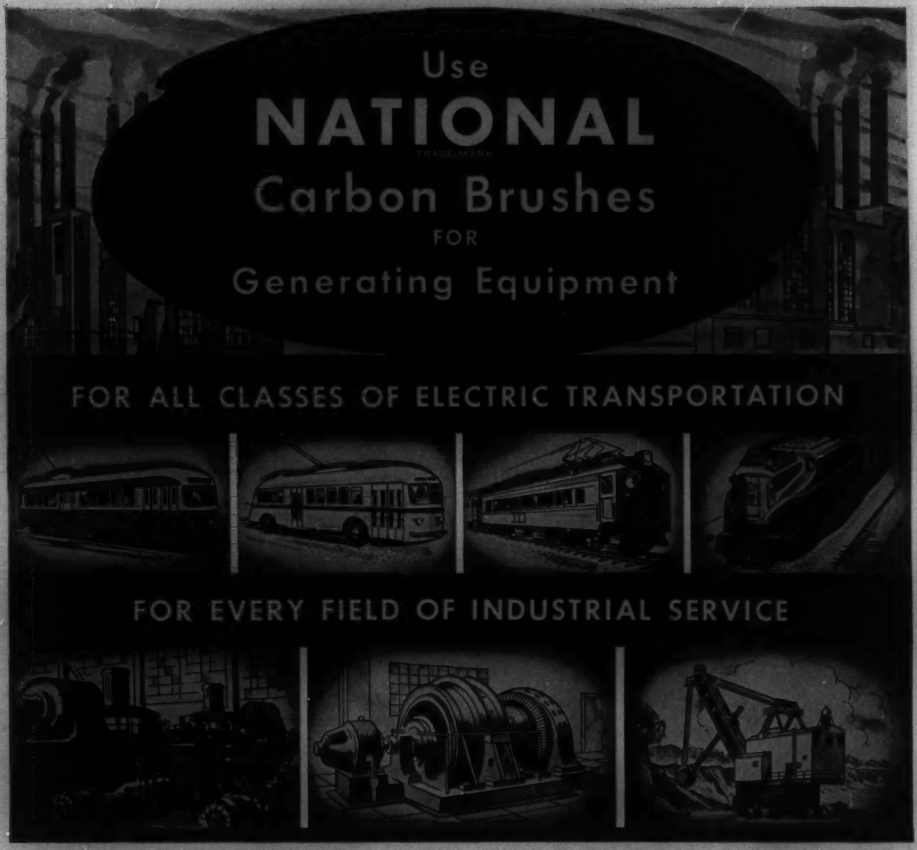
Carrier Current Coupling Capacitor.—A new, larger and improved carrier current coupling capacitor has been introduced by the Cornell-Dubilier Electric Corporation, South Plainfield, N. J. The fog type petticoats give larger creepage distance between terminals; new internal construction affords greater tensile strength. The capacitors are constructed with galvanized malleable iron mounting flanges so that they may be stacked for series, high voltage connection. The base and top are sealed so as to afford leakproof service. The capacitor sections are designed for low resistance and high frequencies, and very low 60-cycle stress. The individual units are now made up to 46 kv., but may be stacked to operate at any desired voltage.



Self-Locking Nuts.—In addition to its standard line of self-locking nuts, the Elastic Stop Nut Corp., Elizabeth, N. J., is now prepared to furnish these nuts in any metal and in any combination of style, size, and thread system. "Elastic Stop" nuts incorporate a resilient, non-metallic collar which takes up all thread play, thus establishing a constant thread contact which holds the nut in position on the bolt regardless of vibration or wear of surrounding parts. They were developed originally for pneumatic tools and other apparatus subject to heavy vibration, and are now widely used on mechanical equipment in every industry. A catalog with graphic explanation of the elastic stop principle and listing the standard nuts available, will be sent by the manufacturer, upon request.

Terminal Connectors.—Designed to accommodate a range of wire or cable sizes, the terminal connector illustrated, introduced by the Burndy Engineering Co., Inc., 459 E. 133rd St., New York City, is a one-piece

assembly so that there are no loose parts to become detached. The pressure strip prevents the clamping screw from damaging the conductor. The entire connector is tinned to prevent corrosion and discoloration and is available in all conductor sizes from No. 14 to 4/0; approved by the Underwriters' Laboratories.



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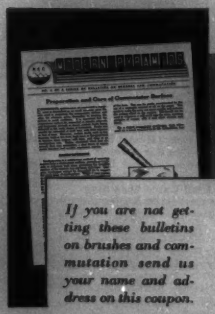

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Papers Presented at South West District Meeting, Houston, Tex., April 17–19, 1939

No.	Authors	Titles of Papers (Some Shortened)
☐ 39-77	Doyle	The Mountain Creek Plant
☐ 39-78	Reynolds	Combined Voltage and Phase-Angle Control Under Load
☐ 39-79	Starbird & Mathis	Some Applications of the Type "J" Carrier System
☐ 39-80	Ilgenfritz, Hunter & Whitman	Line Problems in the 12-Channel Open-Wire Carrier System
☐ 39-81	Vaughan	Out-of-Step Blocking and Selective Tripping
☐ 39-82	Miner	Resonant-Type Constant-Current Regulators
☐ 39-83	Nash & Palmer	Electrical Equipment Used in Seismograph Prospecting
☐ 39-84	Evans	Electricity in an Oil-Field-Equipment Manufacturing Plant
☐ 39-85	Boehne & Weil	Equivalent Electrical and Mechanical Systems
☐ 39-86	Starr	Application of Factory-Built Substations
☐ 39-87	Kennedy & Bancker	Carrier Pilot Relaying
☐ 39-88	Peterson	Improvements in the Construction of Condenser Bushings
☐ 39-89	Reed	Mutual Inductance, etc., Expressed in Terms of Matrices
☐ 39-90	Browder	Signaling Over Zero-Sequence Network
☐ 39-91	Hanna, Oplinger & Valentine	Recent Developments in Generator Voltage Regulation

Papers Presented at North Eastern District Meeting, Springfield, Mass., May 3–5, 1939

☐ 39-92	Faus & Corson	A New Measuring Instrument for Direct Current
☐ 39-93	Laughlin, Pakala & Reagan	Carrier Losses and Interference on Boulder-Los Angeles Line
☐ 39-94	Patterson	Radio as a Means of Bridging Gaps in Telephone Lines
☐ 39-95	Hanna, Oplinger & Mikina	Recent Developments in Speed Regulation
☐ 39-96	Kimbark	Two-Phase Co-ordinates of a Three-Phase Circuit
☐ 39-97	Ross & Sterrett	Hydrogen-Cooled Turbine Generators
☐ 39-98	Hobson & Lewis	Regulating Transformers in Power-System Analysis
☐ 39-99	Bellaschi & Manning	Dielectric Strength of Porcelain
☐ 39-100	Clem	Equivalent Circuit Impedance of Regulating Transformers
☐ 39-101	Goodhue	The Rectifier Calculus
☐ 39-102	Richardson	Turbine-Electric Textile Range Drives
☐ 39-103	Untersee	Characteristics and Power Requirements of Spinning Frames
☐ 39-104	Graves	Electrical Equipment on Machine Tools
☐ 39-105	Snell	The Hydrogen-Cooled Turbine Generator
☐ 39-106	Mortensen & Ryan	Some Factors in the Design of High Speed Turbogenerators
☐ 39-107	Laffoon & Rose	Special Problems of Two-Pole Turbine Generators
☐ 39-108	Paine & Brown	Corona Discharge on Rubber-Insulated Cables
☐ 39-109	Dawes & Humphries	Characteristics of Restricted Ionization
☐ 39-110	Seaman	Modern Trends of Low-Voltage Air Circuit Breakers

Papers Presented at Summer Convention, San Francisco, Calif., June 26–30, 1939

☐ 39-93	Laughlin, Pakala & Reagan	Carrier Losses and Interference on Boulder-Los Angeles Lines
☐ 39-97	Ross & Sterrett	Hydrogen-Cooled Turbine Generators
☐ 39-105	Snell	The Hydrogen-Cooled Turbine Generator
☐ 39-106	Mortensen & Ryan	Some Factors in the Design of High-Speed Turbogenerators
☐ 39-107	Laffoon & Rose	Special Problems of Two-Pole Turbine Generators
☐ 39-111	Whitehead	The Dielectric Strength and the Life of Impregnated Paper
☐ 39-112	Race	Dielectric Strength of Insulating Liquids
☐ 39-113	Race	Tests on Oil Impregnated Paper—IV
☐ 39-114	Holtz	Behavior of Single-Phase A-C Watt-hour Meters at No Load
☐ 39-115	Sorensen	Surge Breakdown Characteristics for Electrical Gaps in Oil
☐ 39-116	Harrison	Ionization Time of Thyratrons
☐ 39-117	Pipes	Transformation Theory of General Static Polyphase Networks
☐ 39-118	Stansbury & Jochem	Capacitor Relay Timing in Industrial Control
☐ 39-119	Markwart	Mingled Hydro- and Steam-Power Production in California
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☐ 39-121	Marti & Taylor	Wave Shape of 30- and 60-Phase Rectifier Groups
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☐ 39-142	Lamberger	Variable-Voltage Equipment for Rotary Drilling Rigs
☐ 39-143	Weeks, Giesecke & Lathrop	Electrical Engineering and the Petroleum Refiner
☐ 39-144	Aggers, Foster & Young	Instruments and Methods of Measuring Radio Noise
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☐ 39-146	d'Humy	Recent Developments in Telegraph Switching

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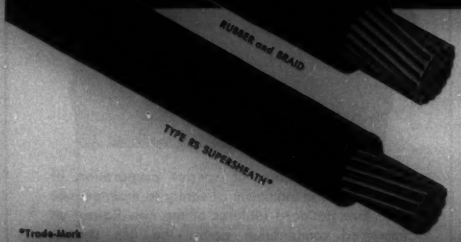

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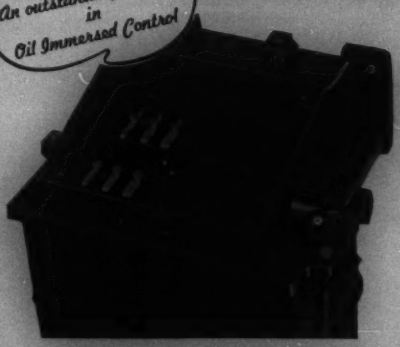

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E.E., B.S., age 24, Tau Beta Pi, 15 mos lab and test work, one yr elec circuit and panel des, now employed, desires pos with opportunity. E-501.

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Weston Elec. Instrument Corp., Newark, N. J.

INSULATING MATERIALS
Cloth
General Electric Co., Bridgeport, Conn.
Minerallac Electric Co., Chicago
Compounds
General Electric Co., Bridgeport, Conn.
Minerallac Electric Co., Chicago
Roebling's Sons Co., John A., Trenton, N. J.
Moulded
General Electric Co., Bridgeport, Conn.
Paper
General Electric Co., Bridgeport, Conn.
Porcelain
Universal Clay Products Co., Sandusky, O.
Tape, Friction
Minerallac Electric Co., Chicago
Okonite Company, The, Passaic, N. J.
Roebling's Sons Co., John A., Trenton, N. J.
Varnishes
General Electric Co., Bridgeport, Conn.
Minerallac Electric Co., Chicago

INSULATORS, PORCELAIN
General Electric Co., Schenectady, N. Y.
Ohio Brass Co., Mansfield, O.
Universal Clay Products Co., Sandusky, O.

LIGHTING EQUIPMENT, OUTDOOR
General Electric Co., Schenectady, N. Y.

LIGHTNING ARRESTERS
General Electric Co., Schenectady, N. Y.

LOAD RECORDERS—CONTROLLERS
Leeds & Northrup Co., Philadelphia

LOCOMOTIVES, ELECTRIC
General Electric Co., Schenectady, N. Y.

METERS, ELECTRICAL
(See INSTRUMENTS, ELECTRICAL)

MOTORS
(See GENERATORS AND MOTORS)

PLASTIC PRODUCTS
General Electric Co., Schenectady, N. Y.

POLE LINE HARDWARE
Malleable Iron Fittings Co., Branford, Conn.
Ohio Brass Co., Mansfield, O.

POLE MOUNTS
Malleable Iron Fittings Co., Branford, Conn.

PORCELAIN, ELECTRIC
Universal Clay Products Co., Sandusky, O.

RECTIFIERS
General Electric Co., Schenectady, N. Y.

REGULATORS, VOLTAGE
General Electric Co., Schenectady, N. Y.
General Radio Co., Cambridge, Mass.
Roller-Smith Co., Bethlehem, Pa.
Sola Electric Co., Chicago, Ill.

RELAYS
General Electric Co., Schenectady, N. Y.
Guardian Elec. Mfg. Co., Chicago, Ill.
I-T-E Circuit Breaker Co., Philadelphia
Roller-Smith Co., Bethlehem, Pa.
Weston Elec. Instrument Corp., Newark, N. J.

RESISTORS
Aerovox Corp., New Bedford, Mass.
General Electric Co., Schenectady, N. Y.
General Radio Co., Cambridge, Mass.
International Resistance Co., Philadelphia
Ohmite Mfg. Co., Chicago

RHEOSTATS, LABORATORY
General Electric Co., Schenectady, N. Y.
International Resistance Co., Philadelphia
Ohmite Mfg. Co., Chicago

SHEETS, ELECTRICAL
Carnegie-Illinois Steel Corp., Pittsburgh

SUB-STATIONS
General Electric Co., Schenectady, N. Y.

SURGE ABSORBERS
Ferranti Electric, Inc., New York

SWITCHBOARDS
General Electric Co., Schenectady, N. Y.
I-T-E Circuit Breaker Co., Philadelphia
Roller-Smith Co., Bethlehem, Pa.

SWITCHES, AUTOMATIC TIME
General Electric Co., Schenectady, N. Y.
Minerallac Electric Co., Chicago

SWITCHES, DISCONNECT
General Electric Co., Schenectady, N. Y.
Roller-Smith Co., Bethlehem, Pa.

SWITCHES, GENERATOR FIELD
I-T-E Circuit Breaker Co., Philadelphia

TOWERS, TRANSMISSION
American Bridge Co., Pittsburgh

TRANSFORMERS
Acme Elec. & Mfg. Co., Cuba, N. Y.
Ferranti Electric, Inc., New York
General Electric Co., Schenectady, N. Y.
General Radio Co., Cambridge, Mass.
Sola Electric Co., Chicago

TURBINE GENERATORS
General Electric Co., Schenectady, N. Y.

TURBINES
General Electric Co., Schenectady, N. Y.

WELDERS, ARC
General Electric Co., Schenectady, N. Y.

WELDING WIRE
American Steel & Wire Co., Chicago
General Electric Co., Schenectady, N. Y.
Roebling's Sons Co., John A., Trenton, N. J.

WIRES AND CABLES
Aluminum
Aluminum Co. of America, Pittsburgh
Armored Cable
American Steel & Wire Co., Chicago
Crescent Ins. Wire & Cable Co., Trenton, N. J.
General Cable Corp., New York
General Electric Co., Schenectady, N. Y.
Kerite Ins. Wire & Cable Co., New York
Okonite Company, The, Passaic, N. J.
Roebling's Sons Co., John A., Trenton, N. J.
Asbestos Covered
American Steel & Wire Co., Chicago
General Cable Corp., New York
General Electric Co., Bridgeport, Conn.
Okonite Company, The, Passaic, N. J.
Roebling's Sons Co., John A., Trenton, N. J.
Bare Copper
American Steel & Wire Co., Chicago
Copperweld Steel Co., Glassport, Pa.
Crescent Ins. Wire & Cable Co., Trenton, N. J.
General Cable Corp., New York
Roebling's Sons Co., John A., Trenton, N. J.
Bronze
Copperweld Steel Co., Glassport, Pa.
Copper Covered Steel
American Steel & Wire Co., Chicago
Copperweld Steel Co., Glassport, Pa.
General Cable Corp., New York
Flexible Cord
American Steel & Wire Co., Chicago
Crescent Ins. Wire & Cable Co., Trenton, N. J.
General Cable Corp., New York
General Electric Co., Schenectady, N. Y.
Okonite Company, The, Passaic, N. J.
Roebling's Sons Co., John A., Trenton, N. J.
Heavy Duty Cord
American Steel & Wire Co., Chicago
Crescent Ins. Wire & Cable Co., Trenton, N. J.
General Cable Corp., New York
Okonite Company, The, Passaic, N. J.
Roebling's Sons Co., John A., Trenton, N. J.
Lead Covered (Paper and Var. Cambric Ins.)
American Steel & Wire Co., Chicago
Crescent Ins. Wire & Cable Co., Trenton, N. J.
General Cable Corp., New York
General Electric Co., Schenectady, N. Y.
Kerite Ins. Wire & Cable Co., New York
Okonite Company, The, Passaic, N. J.
Okonite-Callender Cable Co., Passaic, N. J.
Roebling's Sons Co., John A., Trenton, N. J.
Magnet
American Steel & Wire Co., Chicago
Crescent Ins. Wire & Cable Co., Trenton, N. J.
General Cable Corp., New York
General Electric Co., Schenectady, N. Y.
Roebling's Sons Co., John A., Trenton, N. J.
Rubber Insulated
American Steel & Wire Co., Chicago
Crescent Ins. Wire & Cable Co., Trenton, N. J.
General Cable Corp., New York
General Electric Co., Schenectady, N. Y.
Kerite Ins. Wire & Cable Co., New York
Okonite Company, The, Passaic, N. J.
Roebling's Sons Co., John A., Trenton, N. J.
Tree Wire
American Steel & Wire Co., Chicago
Crescent Ins. Wire & Cable Co., Trenton, N. J.
General Cable Corp., New York
Kerite Ins. Wire & Cable Co., New York
Okonite Company, The, Passaic, N. J.
Roebling's Sons Co., John A., Trenton, N. J.
Weatherproof
American Steel & Wire Co., Chicago
Crescent Ins. Wire & Cable Co., Trenton, N. J.
Copperweld Steel Co., Glassport, Pa.
General Cable Corp., New York
General Electric Co., Schenectady, N. Y.
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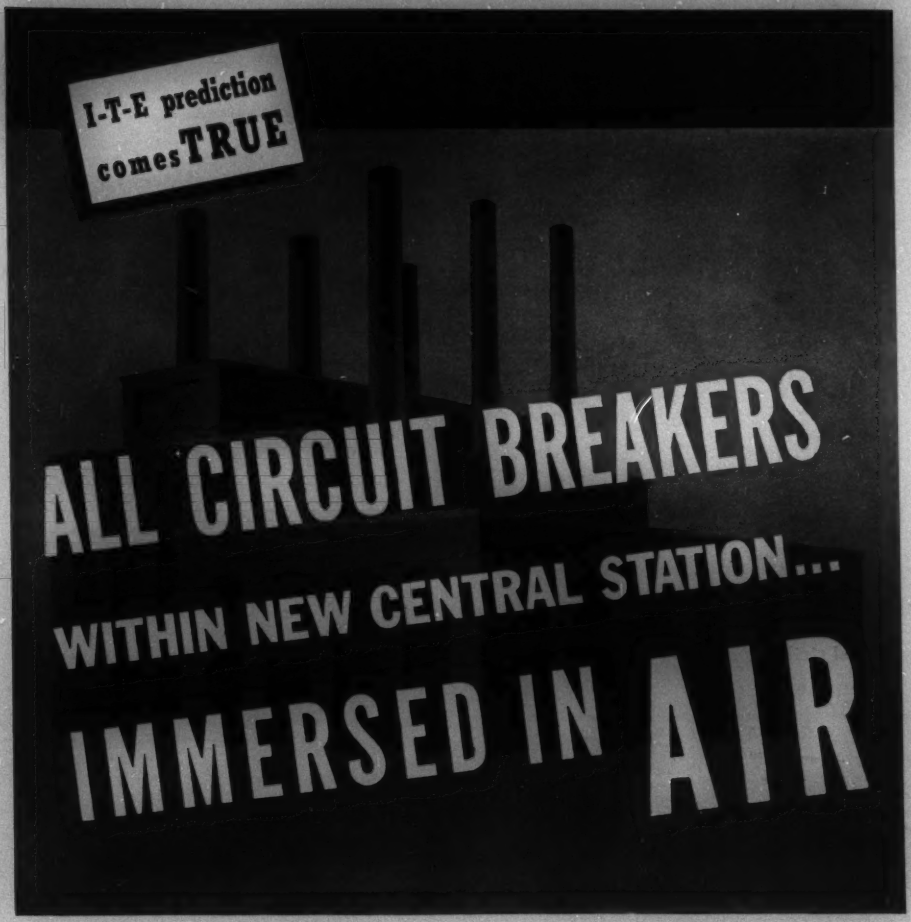

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